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GEOLOGY

BY

THOMAS C. CHAMBERLIN AND ROLLIN D. SALISBURY

Heads of the Departments of Geology and Geography, University of Chicago
Members of the United States Geological Survey
Editors of the Journal of Geology

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THE TRIASSIC PERIOD.

The crustal movements which affected the North American continent during the closing period of the Paleozoic era, and the accompanying changes in geography, have been noted. From the area between the growing Appalachians and the Great Plains the sea was excluded. The surface of Appalachia, lying east of the Appalachian Mountains, and extending eastward perhaps beyond the present coast, the land which throughout the Paleozoic era had furnished sediments to the sinking trough where the Appalachian Mountains were to arise, suffered deformation during the closing stages of the Paleozoic or soon after, and parts of its surface were converted into areas of deposition. These areas were in the form of long and relatively narrow troughs, roughly parallel to the present coast. In them, sediments from the surrounding land were laid down, and constitute the only representative of the Triassic system known in the eastern part of the continent. It is not known that the deformation of the surface of Appalachia brought any part of the present land area beneath the ocean.

In the west, the geographic changes which marked the transition from the Paleozoic were scarcely less important. The more or less open sea of the western interior during the Mississippian and Pennsylvanian periods was largely excluded at the close of the Carboniferous. In the Permian period, it is true, the sea had at least temporary access to an extensive area in the western interior (Vol. II, p. 621); but in the Triassic period the open sea seems to have been completely excluded from this region, though there were still considerable areas of sedimentation between the meridians of 100° and 113°. Some

of these areas were the sites of salt seas, and some of fresh lakes, while still others may have been free from standing water. Within the general area of deposition, many areas of relatively high land probably interrupted the continuity of the sedimentation.

At about the time when the open sea was generally excluded from the western interior, the ocean began to creep in on the western border of the continent, and the shore of the Pacific was presently shifted eastward to the 117th meridian in the latitude of Nevada.

As a result of these changes in geography, the Triassic strata are known in three regions: (1) The Atlantic slope east of the Appalachians; (2) the western interior; and (3) the Pacific coast. The strata in these three regions are so widely separated, and in many ways so unlike, that they will be considered separately.

THE TRIASSIC SYSTEM (NEWARK SERIES) OF THE EAST.

Distribution.—From Nova Scotia on the north to South Carolina on the south there is a series of belts or patches of rock of Triassic age, representing the oldest post-Paleozoic system on the eastern side of the continent. The beds of these several areas have been grouped under the name *Newark*[1] (from Newark, N. J.).

The areas where the strata of the system are now exposed are shown on the accompanying map (Fig. 307). Of their existence east of their exposures nothing is known.

It will be observed that the belts and patches where Newark strata come to the surface are mostly elongate in a northeast-southwest direction, and that their longer axes are roughly parallel to the Appalachian Mountains and to the present coast line. Of the series, there may be said to be four principal areas. These are: (1) the area about the Bay of Fundy; (2) the area in the Connecticut River valley; (3) the long belt extending from the Hudson River in the southern part of New York, through New Jersey, Pennsylvania, and Maryland into Virginia; (4) a number of relatively small disconnected areas in Virginia and North Carolina. From what has preceded, and from the general principles already understood, it is needless to say that the Newark series is unconformable on the older formations on which it rests.

[1] For an account of the Newark series see Russell, Bull. 85, U. S. Geol. Surv., 1892. Full bibliography to date of publication.

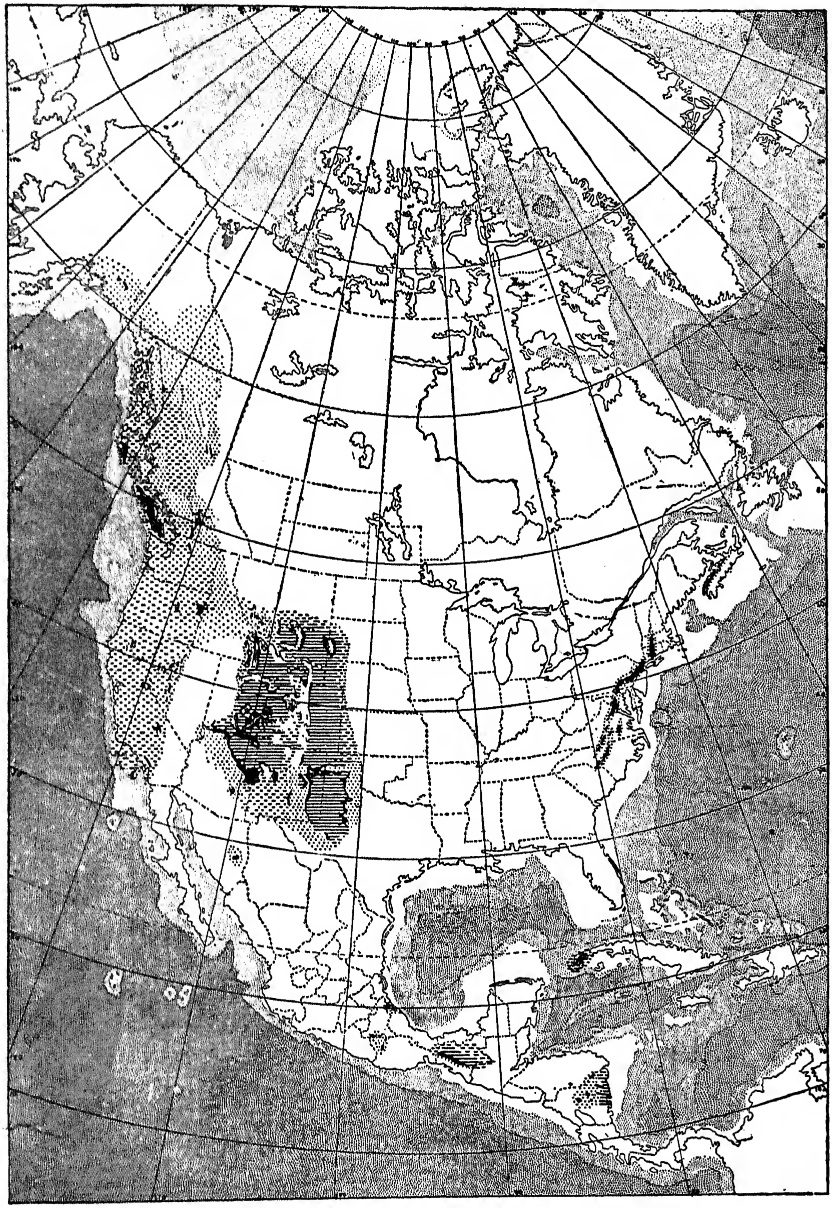


FIG. 307.—Map showing the known distribution of the Triassic system in North America (black areas), with conjectures as to its presence where buried (lined areas), and its absence where it was once present (dotted areas).

The Rocks of the Newark Series.[1]

The rocks of the Newark series are of various sorts, including all the common varieties of fragmental rocks, some of which are here developed in unusual phases. There are abundant conglomerates and some breccias, though sandstones and shales make up the principal mass of the series. Locally, the system contains a little limestone, and in Virginia and North Carolina there is bituminous coal. Elsewhere the shale is sometimes carbonaceous.

The conglomerates.—Wherever standing waters came to occupy those parts of the old land surface which warping had brought low, they found upon it a mantle of decomposed and partially decomposed rock, out of which arose basal conglomerates, made up partly of the local rock (crystalline schists), but largely of its most resistant part—the material of the quartz veins which affected it. At the same time, drainage from the adjacent lands doubtless contributed sediment to the areas of deposition.

The conditions for conglomerate formation were present for long periods in some places, as shown by the thickness of the beds; but they were present at the same place at different times, for the conglomerate is not simply basal. Thus along the northwestern border of the series in New Jersey, beds of coarse conglomerate at various horizons represent the shore phase of beds which grade out into sandstone, and even into shale. As now exposed, the conglomerates are seen in greatest development along the eastern border of the New England area, and along the western borders of the areas farther south.

The chief constituent of the Newark conglomerate is quartz, as already noted, but in places it contains much quartzite and crystalline schist. Again, in some places in New York and New Jersey, as well as at points farther south, the principal constituent is limestone. Locally (some parts of New Jersey) so little else enters into its make-up that it is quarried and burned for lime. The masses of limestone involved are occasionally several feet in diameter.

To appreciate the exceptional character of the conglomerate it may be recalled that limestone, on decomposition, is mainly dissolved, the insoluble part only becoming available for sediments.

[1] The Connecticut valley and New York-Virginia areas are best known, and the descriptions of the formations here given apply especially to them.

This is usually fine and of an earthy nature, and gives rise to mud beds; or if there be abundant chert in the limestone, the insoluble residue may be coarse, giving rise to gravel. Under ordinary circumstances, streams do not break up limestone and transport it in masses, giving rise to limestone conglomerate at their debouchures. Had there been limestone cliffs against which the waves of the Triassic waters beat, or had there been scarps, at the bases of which talus from limestone accumulated, the occurrence of limestone conglomerate would not be strange, for in such situations conglomerate and breccia containing a large proportion of limestone may be formed. But at most points where the limestone conglomerate occurs, there is now nothing to indicate that the areas of Triassic sedimentation were bordered by limestone. If they were, the surface exposures of the original formation have been destroyed, while its derivative formation remains. Either erosion (Figs. 308 and 309) or faulting (Figs. 310 and 311) might accomplish this result. If there

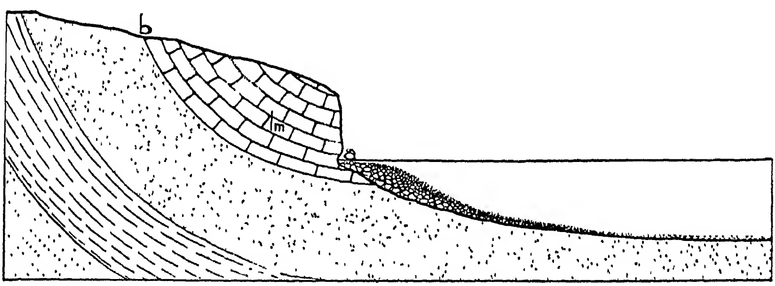


FIG. 308.—Diagram illustrating the manner in which limestone conglomerate (below *a*) might be formed along shore. *lm* = limestone. (Compare Fig. 309.)

was faulting while the deposition of the series was in progress, fault scarps, involving limestone, may have appeared about the borders of the area of deposition. In this case, waves and descending streams might have provided the material for the limestone conglomerate. With the limestone, there is more or less other material derived from the local rock formations; but at some points there are occasional bowlders which do not correspond with any known formation of the region. That they had a distant origin cannot, however, be asserted. They may have come from formations now concealed or destroyed.

The exceptional coarseness of the conglomerate, at least locally,

has been thought to call for some exceptional means of transportation. On this ground, it was long since conjectured that it was formed at a time when glaciers existed in the eastern part of the United States. Furthermore, glacial action, if operative in regions where there was limestone, might produce conglomerate comparable in constitution to that here found. It should be noted, however, that it was the supposed demand for some exceptional agent of transportation, rather than any direct evidence, which suggested the existence of glacier ice. The constitution of the conglomerate at most points, and especially the characteristics of its constituent parts, do not seem to support the suggestion. In general, the materials are too well assorted to be the immediate product of glaciation, and the stones and bowlders are

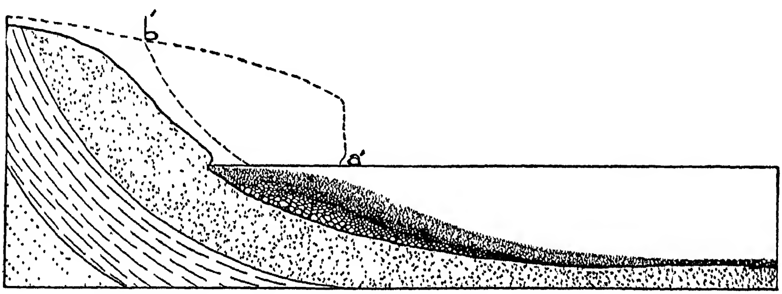


FIG. 309.—Diagram showing how the limestone which gives rise to the conglomerate might have been removed by erosion, leaving some of the limestone conglomerate.

not only not striated, but generally possess forms not characteristic of ice-worn bowlders. These objections to the hypothesis of the glacial origin of the conglomerate lose much of their force if the formation be looked upon as a deposit in water to which glacial drainage contributed; but in the absence of all certain evidence of glacial or glacio-fluvial origin, it seems more prudent to regard the conglomerate as an exceptional phase of a shore formation.

The sandstone and shale.—The great body of the Newark series is sandstone and shale, and both possess three or four notable characteristics. First, their prevalent color is red, though there are shales which are black, and sandstones which are gray. Second, except locally, the series is poor in fossils, and those which exist are of such a character as to indicate that the beds were not accumulated in open sea-water. Third, some of the sandstone contains a considerable

amount of feldspar, derived, no doubt, from the bordering areas of metamorphic rocks. Fourth, both the sandstone and shale contain considerable quantities of mica.

In general, it may be said that the crystalline schists adjacent were the principal source of the materials entering into the clastic part of this series, but where it borders formations of other sorts, they made their appropriate contributions. The limestone and the coal of the series are local, and of slight thickness.

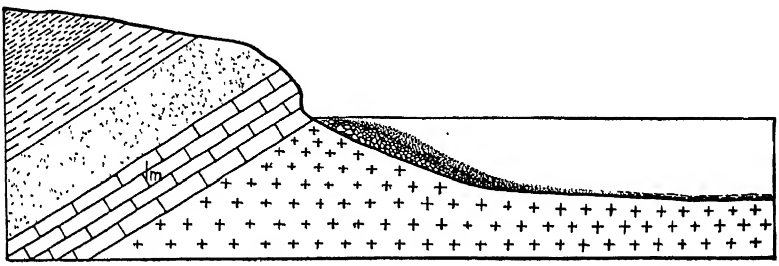


Fig. 310.

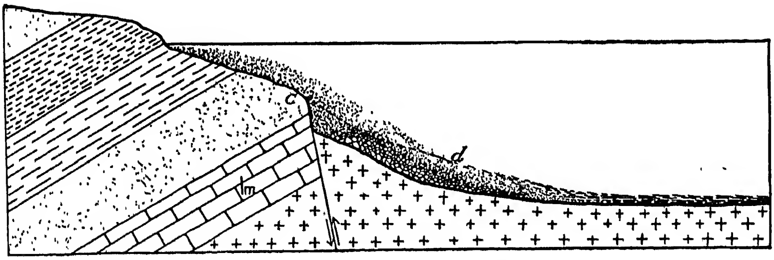


Fig. 311.

Fig. 310 shows limestone conglomerate forming along shore, where waves beat against a limestone cliff (*lm*), while Fig. 311 shows how faulting might conceal the limestone which furnished the material for the conglomerate. Subsequent erosion might expose the limestone conglomerate, without exposing the formation from which it was made.

Conditions of origin.—The character of the Newark formations and their fossils, mainly land plants, footprints of reptiles, and fresh- or brackish-water fishes, point to the conclusion that they are of continental rather than of marine origin, though the precise manner in which they were laid down is not known. That deformation of the surface of Appalachia, which had been reduced nearly to planeness by erosion, gave rise to elongated depressions in which the Triassic sediments were

deposited, seems certain. The depressions may have been due to warping or to faulting, or partly to the one and partly to the other

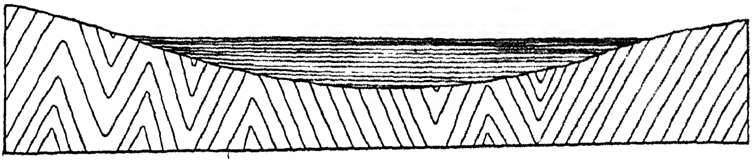


FIG. 312.—Diagram showing the development of a trough, now partly filled by sediment, by warping.

(Figs. 312 and 313), and their development may have continued as deposition proceeded. Some of them may have been the sites of broad river valleys,[1] which, in the general uneasiness which marked the close of the Paleozoic era, were brought into such an attitude as to become sites of deposition. It is to be noted that deposits of the type represented by the Newark series imply warping, rather than depression.

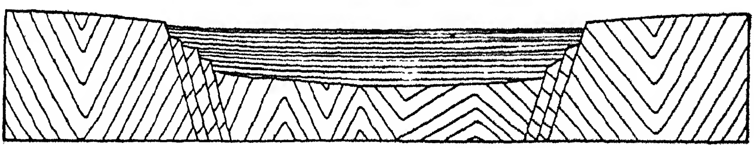


FIG. 313.—Diagram showing the development of a trough, by faulting.

The warping may have been the uplift of the surroundings of the areas of deposition, rather than the depression of those areas; or it may have involved the depression of the areas of deposition as well as the uplift of their surroundings. The deposits now making in the Great Basin afford some analogy. However formed, the depressions (relative) in the surface of the present Piedmont region became the sites of lakes, bays, estuaries, dry basins, or of aggrading rivers. Lacustrine, estuarine, and fluviatile conditions may have alternated from time to time in the various troughs where sedimentation was in progress, and the sea may have gained access to some of them from time to time.

Since the Trias of the Connecticut valley and of the areas south and west of the Delaware are bordered on either side by older terranes, it is easy to see how the areas of deposition might have been enclosed. But from the Hudson to the Delaware the series is bordered

[1] Shaler and Woodworth, 19th Ann. Rept. U. S. Geol. Surv., Pt. II, pp. 399–407.

on the southeast by younger (Cretaceous) beds. The barrier which shut in this area of Trias on the southeast has been buried, but its position was probably not far from the present southeast boundary of the Triassic system in New Jersey. The older rocks are at or near the surface at various points along this line.

The considerable thickness of the sediments, together with the decisive evidences of shallow-water or subaërial origin, such as ripple-marks, sun-cracks, tracks of land animals, etc., which they bear, indicate either that inclined deposition prevailed, or that subsidence of the areas of sedimentation, either by bowing or faulting, accompanied the deposition. For the adequate supply of the detrital material, it would seem that the lands bordering the areas of deposition were raised, relatively, as the troughs filled. These relations would account for the continued supply of coarse material which the series shows. Since the sediments were predominantly the products of the chemical decomposition of the ancient rocks, rather than the product of mechanical disruption, it is probable that the surrounding lands were not generally high.

The prevalent redness of the formations, their structure, the presence locally of limestone not known to be of marine origin, the existence of coal-beds in some regions, and the character and paucity of the fossils, indicate that the sediments accumulated subaërially, or in water which was neither altogether fresh nor altogether salt for any long period of time. The general conditions of accumulation may have been similar to those under which the Catskill formation was deposited at an earlier time.

Former extent.—It is possible, and perhaps probable, that the outlying areas of the Newark series from Virginia to South Carolina were once connected with one another, and with the Virginia-New York area, though such connection has never been demonstrated. It has been suggested, though with little basis, that the Newark of the Connecticut valley was once connected with that of Acadia. It has been thought [1] that the New York-Virginia area was once connected with the New England area, and that, as in the preceding case, the separation was effected by erosion. This suggestion, however, does not seem well founded. A formation of so great extent as such a

[1] Russell, N. Y. Acad. Sci., Ann., Vol. I, 1878; and Am. Nat., Vol. XIV, 1880, pp. 703–12; also Hobbs, Bull. G. S. A., Vol. XIII, pp. 139–148.

connection would imply would possibly make it necessary to assign to it a marine origin; but the paucity of fossils, and the character of those which are found, are opposed to this suggestion. Furthermore the nature of the series itself, and especially the fact that many of the beds at the borders of the present areas seem to have been deposited near shore, indicates that the strata were never as extensive as their union into a single area would imply. That the several areas of the Newark series have been reduced by erosion is certain from the occasional outliers, but nothing now known proves that their original borders were more than a few miles beyond their present borders.

South of New Jersey and Pennsylvania, the Newark beds are on the whole less red than to the north, and contain less conglomerate and more carbonaceous matter.

Subdivisions.—Until recently, the Newark series has not been subdivided, but it has now been shown that in New Jersey it is divisible into three somewhat distinct formations.[1] Of the lowest (*Stockton*), arkose sandstone and conglomerate are the most characteristic sorts of rock. A hard black shale (*Lockatong*) is the most conspicuous part of the middle formation; while red shale and sandstone make up the principal part of the uppermost (*Brunswick*). This classification has not been extended beyond the State, though the same formations cross the Delaware into Pennsylvania. In Connecticut, also, three main divisions are recognized,[2] and in the Richmond area two.[3]

Igneous rocks associated.—Associated with the sedimentary beds of the Newark series there is much igneous rock. The igneous rock occurs partly in dikes, but chiefly in sheets interbedded with the shales and sandstones. Some of the sheets are extrusive, having been poured out on the surface of the inferior beds and subsequently covered by the superior ones; others are intrusive (*sills*), having been forced in between the layers of sedimentary rocks after the latter were deposited. In New England, the igneous rocks are mostly extrusive, while in New Jersey the proportion of intrusive sheets is greater. Certain isolated bodies of igneous rock may represent volcanic plugs. The sheets of igneous rock (really diabase, though usually called trap) vary in thickness from a few to several hundred feet.

[1] Kummel, Ann. Rept. of the State Geologist of New Jersey, 1896.
[2] Davis, 18th Ann. Rept. U. S. Geol. Surv., Pt. II.
[3] Shaler and Woodworth, 19th Ann. Rept. U. S. Geol. Surv., Pt. II.

The means of distinguishing extrusive lava sheets from sills are various, though all criteria are not usually applicable in any one spot. Some of these criteria are as follows: (1) The upper surface of an extrusive sheet is likely to be more or less scoriaceous; (2) the basal portion of the sedimentary rock overlying an extrusive sheet is likely to contain fragments derived from the igneous rock beneath; (3) the base of the clastic bed above an extrusive sheet has not been baked by the heat of the underlying lava. In the case of the intrusive lava sheets, or sills, on the other hand, (1) the overlying sedimentary beds, as well as those below, have been affected by heat; (2) the upper portion of the lava is not likely to be notably scoriaceous; (3) the overlying clastic beds do not contain fragments of the igneous rock; (4) the upper part of the igneous rock may contain fragments of the overlying sedimentary rock; (5) intrusive sheets are likely to send off small dikes or stringers of lava which cut through few or many of the layers of the overlying sedimentary rock; and (6) the intrusive sheet

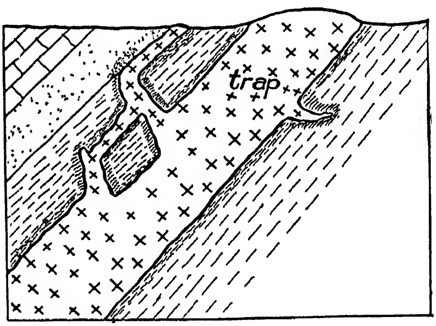


FIG. 314.—Diagram showing a sheet of intrusive rock (sill).

itself may cross layers. Fig. 314 shows some of the characteristics of an intrusive sheet, or sill.

Structure.—The structure of the Newark series is generally monoclinical. In the Connecticut River valley[1] the dip is 10° to 25° (usually 20° to 23°) to the eastward (Fig. 316). The strata are otherwise somewhat deformed, though never closely folded. In addition

[1] For an excellent summary of the Trias of Connecticut, see Davis, 7th Ann. Rept. U. S. Geol. Surv. A fuller and later account is given in the 18th Ann Rept., Pt. II. See also Emerson, the Holyoke folio, U. S. Geol. Surv., and for the interesting Pomperaug area, Hobbs, 21st Ann. Rept. U. S. Geol. Surv., Pt. III.

to the tilting and incipient folding, the series is extensively faulted, and that in a somewhat complicated manner. Some of the faults are strike faults (parallel to the strike), some dip faults (right angles to the strike), while others are oblique in various degrees. There is also a fault or a series of faults along the eastern margin of the series. The faults, affecting as they do a series of variable hardness (the trap being much harder than the clastic beds), have determined many of the peculiar topographic features of the Connecticut River basin, and some of the details of its outlines. The faulting has also given

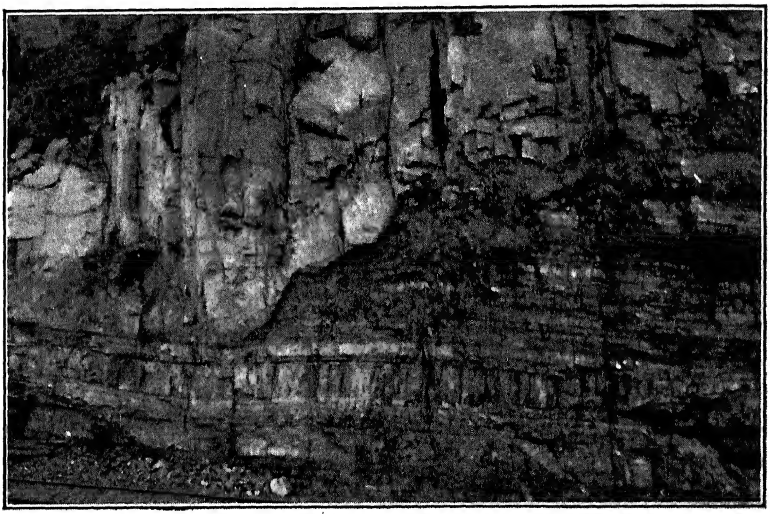


FIG. 315.—Contact of intrusive rock with sedimentary. Palisade Ridge, N. J.

rise to very notable peculiarities of outcrop. This is best illustrated by the outcrops of the trap sheets (Figs. 318, 319, and 321).

In the New York-Virginia area the structure is likewise monoclinal, but the general direction of dip is to the northwest (10°-15°). This contrast of dips between the New England and New Jersey areas was thought to give color to the hypothesis that the strata of the two areas are parts of one huge anticline from the broad crest of which the beds have been removed. As in New England, the beds of the New York-Virginia area are never closely folded, though several broad anticlines and synclines have been shown to exist. The series of this area is also extensively faulted, the total number of faults known in

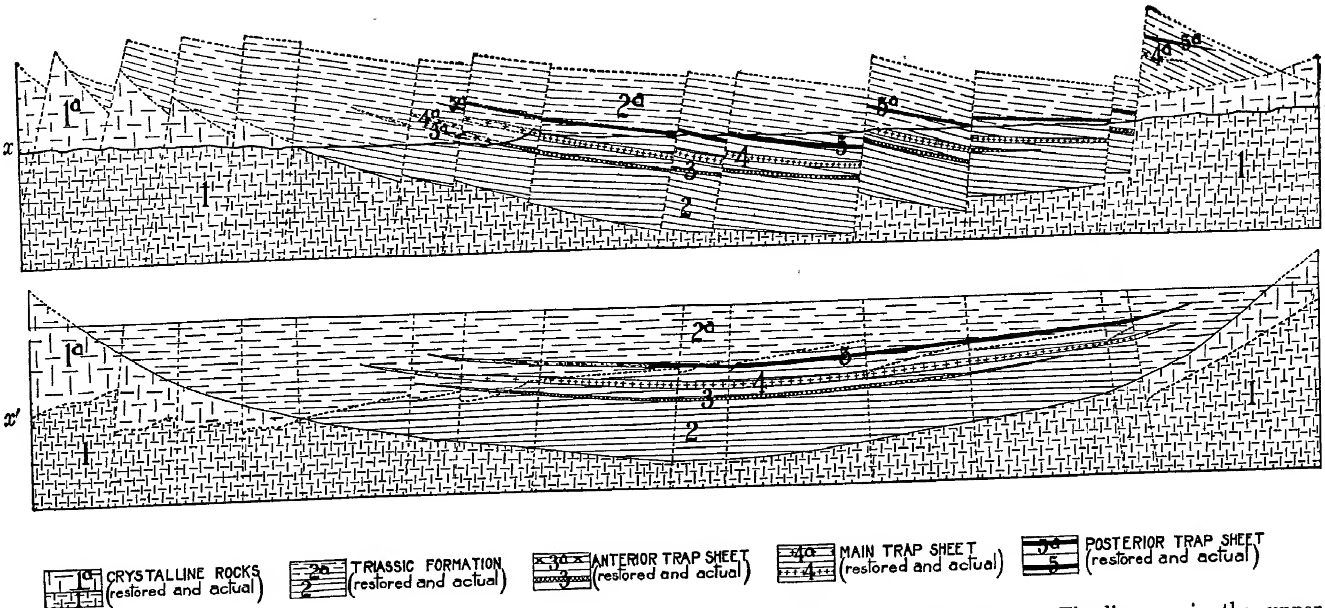


FIG. 316.—Diagram illustrating the structure of the Newark series in the Connecticut River valley. The line xy, in the upper diagram, represents the present surface, and shows the structure of the Newark beds (all above 1) where they come to the surface. The top line of the figure represents the surface as it would have been if erosion had not been operative since the faulting. The lower diagram shows the formations as they are conceived to have been before deformation and faulting. The broken line $x'y'$ corresponds with the line xy of the upper diagram. (Davis, U. S. Geol. Surv.)

New Jersey and New York alone being about 75.[1] Most of these faults are small, but two of them are of the first order. These two

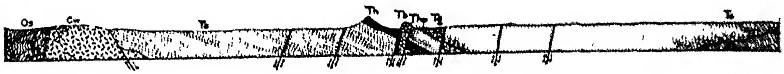


FIG. 317.—Section showing the structure of the Newark series, just north of Holyoke, Mass. *Os* = Savoy schist, probably Ordovician; *Cw* = granite of Carboniferous age; *Ts* = Sugarloaf arkose; *Tg* = Granby tuff; *Tb* = Blackrock diabase (intrusive); *Th* = Holyoke diabase (extrusive), and *Thp* = Hampden diabase (extrusive), members of the Newark series of the Triassic. (Emerson, U. S. Geol. Surv.)

are strike faults, each of such magnitude as to cause the repetition at the surface in western New Jersey of all three divisions (Stockton,

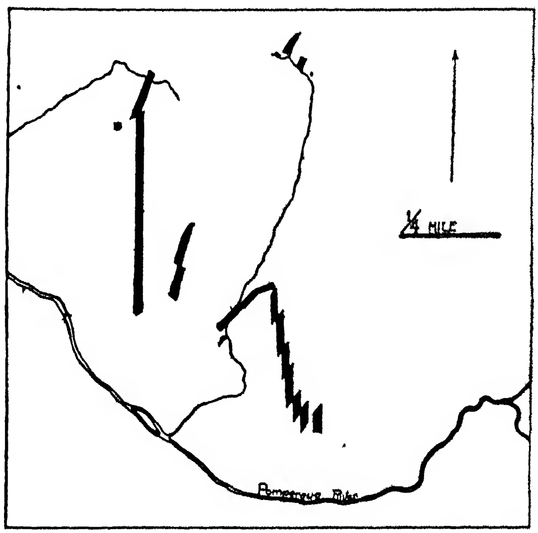


FIG. 318.—Map showing the area where a sheet of igneous rock now appears at the surface. The peculiarities of distribution are the result of faulting. (Hobbs U. S. Geol. Surv.)

Lockatong, and Brunswick) of the Newark series (Fig. 321). These

[1] Kümmel, Jour. Geol., Vol. VII, pp. 23–52—an excellent summary of the Newark series of New York and New Jersey. More detailed descriptions of these faults, and the structure of the New Jersey-Newark generally, are set forth by the same author in the Annual Reports of the State Geologist of New Jersey for the years 1896 and 1897, and more briefly in the Journal of Geology, Vol. V, 1897, p. 541. Some of the faults of the Newark in New Jersey had been earlier recognized by Cook, Smock, Lewis, Darton, Russell, Lyman, and others, described elsewhere. See also New York folio, U. S. Geol. Surv.

faults are continued into Pennsylvania.[1] Of the numerous small faults, few have a throw of more than 200 feet.

Of the southern areas, the Richmond area is best known.[2] As

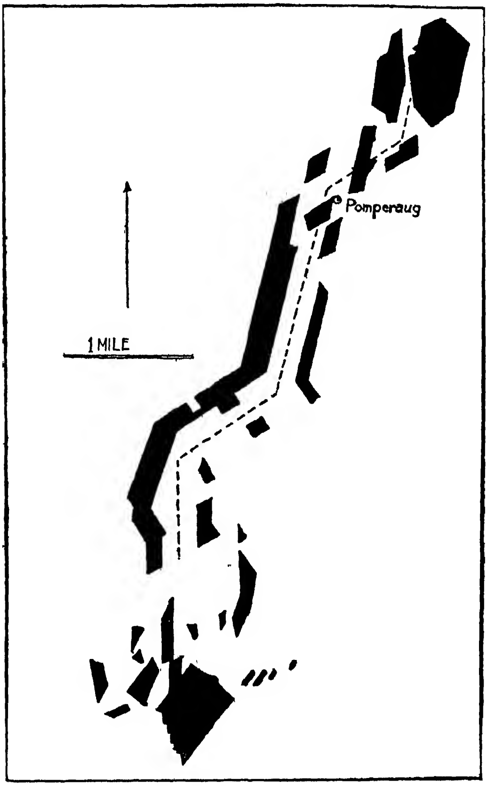


Fig. 319.—Map showing the surface distribution of a sheet of igneous rock in the Pomperaug area of Connecticut. The peculiarities of surface arrangement are due to faulting. (Hobbs, U. S. Geol. Surv.)

farther north, the beds here are much faulted and little folded (Fig. 322). The faulting is clearly shown by the surface distribution of the series (Fig. 323). The trough-like basin which the Newark of this area occupies, is thought to be the result of faulting rather than of pre-Triassic topography. The Newark of this area contains a good

[1] Lyman, Report on the New Red Rock of Bucks and Montgomery counties (Pa.), State Geol. Surv., Final Rept., Vol. III, Pt. II.

[2] Shaler and Woodworth, 19th Ann. Rept. U. S. Geol. Surv., Pt. II.

deal of igneous rock (diabase), mostly in the form of intrusive sheets or sills. The coal, of which there are several beds in the lower part

FIG. 320.—Section across the Palisade Ridge and the Hudson River. *fgn* = Fordham gneiss, Pre-Cambrian; *€Os* = Stockbridge dolomite, Cambrian-Ordovician; *Tn* = Newark; *Tp* = Palisade diabase (intrusive). The surface of *€Os* near the center of the section is below sea-level (Hudson River). The cliff to the left of *€Os* is the Palisade Ridge. (Darton, U. S. Geol. Surv.)

of the series, has sometimes been coked in the vicinity of the igneous intrusions.[1]

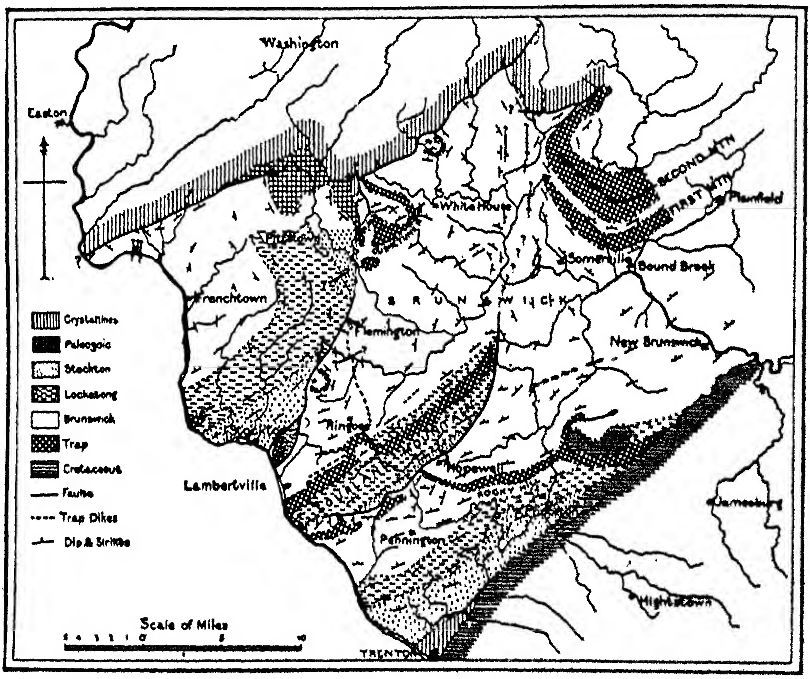


FIG. 321.—Map showing the surface distribution of the several subdivisions of the Newark series in New Jersey. The threefold outcrop of each principal division, near the Delaware River, is shown. (Kümmel, Geol. Surv. of New Jersey.)

In most of the area south of the New York-Virginia area, the dip of the beds is to the northwest, though in one of the eastern patches it

[1] For Trias of Maryland, see Md. Geol. Surv., Vol. I. For portions of the Triassic in Va. and W. Va., see Harper's Ferry (Va.-Md.) and Monterey (Va.-W. Va.) folios.

is to the east, while still another appears to represent the bottom of an old syncline. There is, on the whole, less evidence of disturbance at the close of the Triassic period in this latitude than farther north. The faulting is less, though by no means absent,[1] and igneous rock is less abundant or even wanting. The coal-beds, of considerable thickness in this region, indicate conditions of stability during long intervals of time.[2]

Thickness.—The thickness of the Newark series is variable and, on account of the faulting, difficult of determination. In the Richmond area of Virginia, the thickness is estimated at something more than 3000 feet. In the areas farther south, the thickness is less, though generally unmeasured. In New England, the thickness is estimated

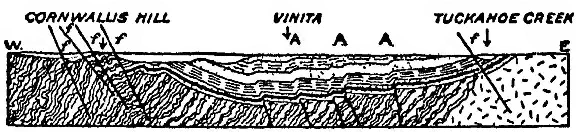


FIG. 322.—Structure of the Newark series on the James River, Richmond area, Va. *AA*, minor flexures; *ff*, faults. Structure of the deeper parts hypothetical. The heavy black band represents coal. (Shaler and Woodworth, U. S. Geol. Surv.)

at 7000 to 10,000 feet, and in New Jersey 12,000 to 15,000 feet. Undiscovered faults may exist which, by repeating beds, have led to exaggerated estimates.

Correlation.—The structural relations of the Newark series in the United States would not determine its age. The formations lie unconformably on rock which is mainly pre-Cambrian, and they are overlain unconformably by Cretaceous beds. About the Bay of Fundy, however, the rocks lie unconformably on the Carboniferous and early Permian. The physical relations of the Newark series therefore show that it is post-early-Permian, and pre-Cretaceous. Between the Permian and the Cretaceous there are two periods, the Triassic and the Jurassic. In the reference of the series to the former, the chief reliance is usually placed on the fossils, and on the same basis the series is believed to represent only the later part of the period.

There is another reason for believing the Newark series to be older

[1] Keith, Harper's Ferry, Va.-Md.-W. Va. folio, U. S. Geol. Surv.

[2] Glenn, Am. Geol., Vol. XXIII, pp. 375–9.

than Jurassic. The physical relations of the Newark beds to the Cretaceous show that before the deposition of the latter, the former had been uplifted, tilted, faulted, and subjected to a period of erosion

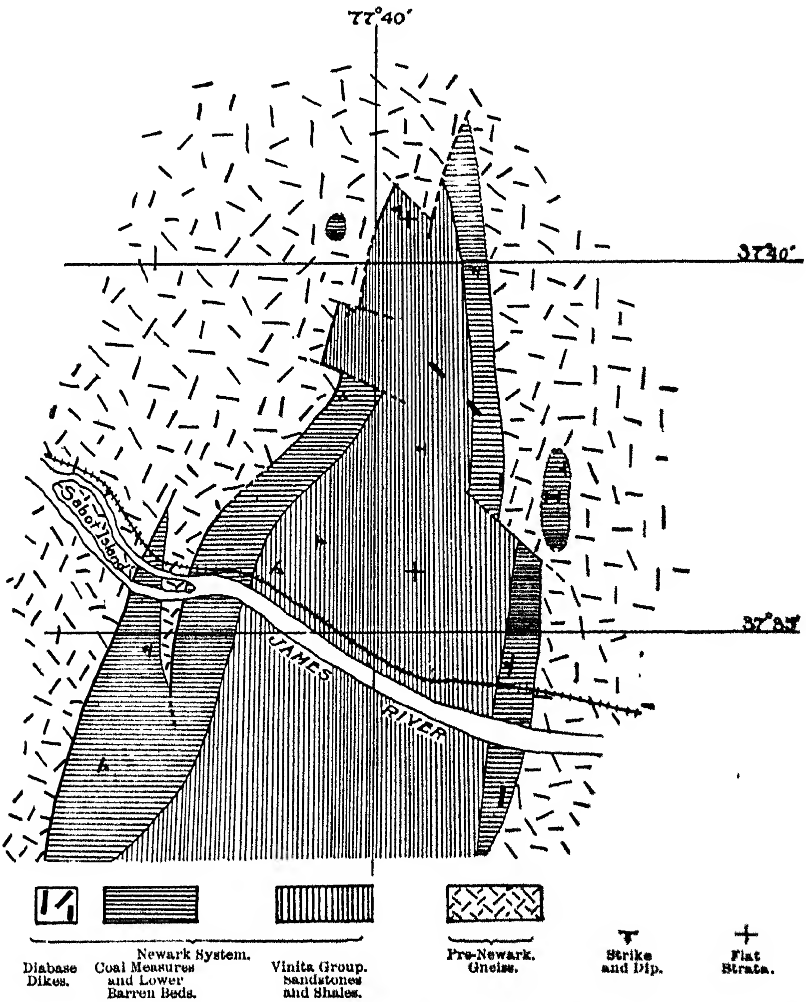


FIG. 323.—Map of the northern part of the Richmond area of the Triassic system, showing the effect of faults on the outcrops of the several members of the series, and on their relations to associated formations. (Shaler and Woodworth, U. S. Geol. Surv.)

sufficiently long to reduce the area where they occur essentially to base-level. The time involved must have been very great, for the hard trap, as well as the softer sedimentary formations, was brought

low. On physical grounds, therefore, there would be ample justification for referring the Newark series to the earlier, rather than to the

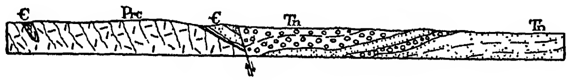


FIG. 324.—Diagram showing structure of the Triassic beds and their relation to older terranes, southeast of Harper's Ferry, in Virginia. *Prc*=Cacoctin schist, Proterozoic; *€*. Cambrian; *Tn*, Newark series, Triassic. (Keith, U. S. Geol. Surv.)

later part of the time-interval between the Permian and the Cretaceous.

Physiography of the Newark of New England and New Jersey.

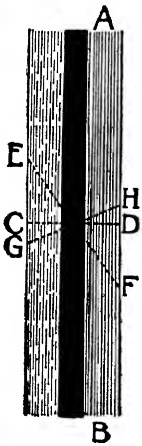
The trap ridges of New England and New Jersey illustrate so clearly several fundamental principles of physiography and structural geology that a few points in their history are here sketched.

Subsequent to its peneplanation in pre-Cretaceous or early Cretaceous time, the area covered by Triassic beds was elevated, and a new cycle of erosion inaugurated. In this post-Cretaceous cycle of erosion, most of the sedimentary beds were degraded readily, while the trap, being notably more resistant, withstood erosion more effectively and came to stand out in conspicuous ridges. Many of the prominent ridges in the Connecticut valley, including such elevations as the Holyoke Range, Toket, Pond, Lamentation, and Farmington Mountains, are simply the outcropping edges of trap sheets isolated by the removal of the less resistant shale and sandstone. The Watchung Mountains of New Jersey, and the Palisade Ridge along the lower Hudson, as well as many other elevations of that and adjoining States, owe their origin to a similar sequence of events. In New Jersey, the Lockatong formation, as well as the trap sheets, is a ridge-maker.

That deformation other than tilting affected the Triassic system is shown by numerous phenomena. Among these is the curvature of some of the trap ridges, such as Cushetunk Mountain (Fig. 321), the rock of which is an extrusive sheet of diabase. Since the general direction of dip of the Newark series in New Jersey is to the northwest, the curvature means a syncline, the axis of which is northwest and southeast. This folding probably accompanied the first deformation to which the Newark series was subject, rather than that which followed the Cretaceous base-leveling, for the curved crest is approximately level. The curvature of First and Second Mountains (Fig. 321) is probably to be explained in the same way. The trap ridges of the Connecticut valley show similar phenomena.

The trap outcrops of the Connecticut valley illustrate the manner in which faulted strata of unequal hardness may come to express themselves topographically, and their study throws light both on structural and physiographic problems.

A series of illustrations will make clear the problems involved; but to understand them, it should be recalled that the general structure of the series is monoclinal, with the general dip to the east. If the dip were always to the east (or in any constant direction), faults parallel to the strike (strike faults) would produce one series of phenomena, faults at right angles to the strike (dip faults, *CD*, Fig. 325) would produce another series, and faults oblique to the strike



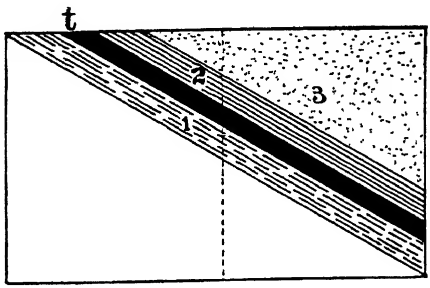


FIG. 325. FIG. 326.

FIG. 325.—Diagram showing the position of dip faults, oblique faults, etc. The black band represents the outcrop of a layer of rock on a plane surface, and therefore the strike of the rock. AB = the direction of a strike fault, CD the direction of a dip fault, and GH and EF directions of oblique faults.

FIG. 326.—Diagrammatic section showing dipping beds.

(*GH* and *EF*, Fig. 325) would produce still another (see also Vol. I, pp. 521 and 525).

1. Suppose a series of sedimentary beds with constant dip to the east to have a single trap sheet, *t*, interbedded (Fig. 326). Suppose the series to be affected by a strike fault with upthrow to the east. After erosion has cut down the upthrow side to the level of the other, any layer (say the trap) will outcrop in two parallel belts (*t*, Fig. 327). Had the upthrow been to the west (the dip being east) a repetition might not have occurred, and the outcrop of a given layer, such as the trap, might have been eliminated. If the faulted surface had been reduced to the level of *AB* (Fig. 328), the trap sheet would not have appeared at the surface.

2. Assume the same series of beds to be affected by a dip fault (outcrop of fault plane along *CD*, Fig. 325) with the upthrow to the south. After erosion has brought the upthrow side to the level of the other, the layer of trap will outcrop in the manner shown in Fig. 329. If the upthrow had been to the north, the result would have been as shown in Fig. 330; that is, in the case of a dip fault, the outcrop of a layer on the upthrow side is (after erosion) shifted in the direc-

tion of dip. For a given throw, the horizontal shifting is greater, the less the dip and the greater the amount of the degradation of the upthrow side.

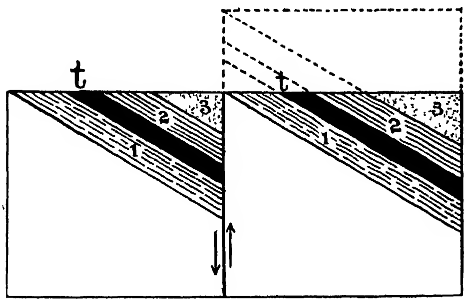


FIG. 327.—Same as Fig. 326, after being faulted along the strike, and after planation. The several layers are repeated at the surface.

3. Let the same series of beds be assumed to be affected by an oblique fault. Let the plane of the fault be east-northeast by west-southwest (along *GH*, Fig. 325) and the upthrow on the south-southeast side. After erosion has reduced the surface to a common level, the trap sheet will outcrop as shown in Fig. 331; that is, the outcrop of the trap is offset with overlap. Had the upthrow been to the north-northeast, the outcrop would have appeared as in Fig. 332; that is, the outcrop of the trap would have been offset with a gap. Had the faulting been along the line *EF*, Fig. 325, the result would have been illustrated by Fig. 333, in case of upthrow to the northeast.

4. If, instead of having a constant dip to the east the strata were slightly deformed, that is, thrown into broad synclines and anticlines, the phenomena

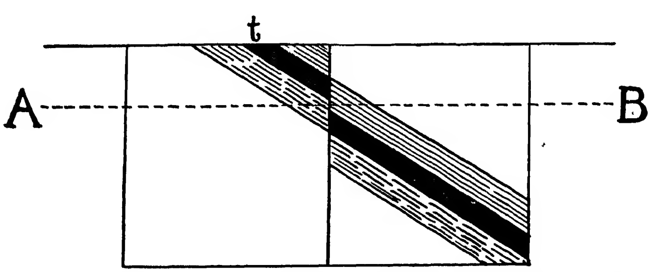


FIG. 328.—Same as Fig. 326, after faulting with downthrow at the right. When erosion has reduced the surface to *AB* certain strata, as *t*, fail to appear at the surface.

would be slightly different. If such a series as the Newark, dipping to the east, be affected by a broad syncline, any given layer, after base-leveling, will not outcrop in a straight line, but in a curve (Fig. 334). If the deformation had been an anticline instead of a syncline, the curve would have been in the opposite direction; that is, the outcrop curves away from the prevalent dip in the

axis of a syncline and toward it in the axis of an anticline. This explains the curvature of some of the trap ridges in New England.

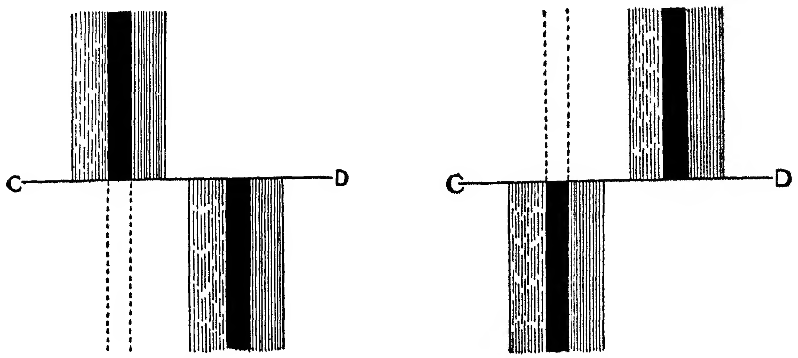


FIG. 329. FIG. 330.

FIG. 329.—Diagram illustrating the effect of a dip fault on outcrops where the structure is like that shown in Fig. 326, after the faulted surface has been reduced to a plane. The south side was the upthrow side.
FIG. 330.—Same as Fig. 329, except that the opposite side is the upthrow side.

5. Where the deformed strata are affected by faults, the curved outcrops may be repeated in parallel positions (strike faults). They may be offset with-

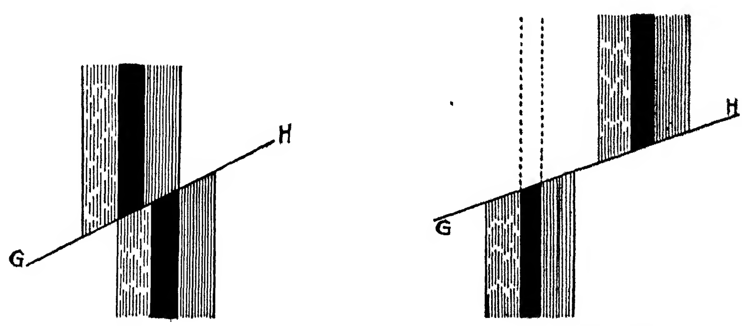


FIG. 331. FIG. 332.

FIG. 331.—Effect of an oblique fault on the outcrop of beds, where the structure before faulting was that shown in Fig. 326. The south-southeast side was the upthrow side, and the diagram represents the surface after it has been reduced to a plane, subsequent to the faulting.
FIG. 332.—Same as the last, except that the fault was greater, and the north-northwest side the upthrow side.

out gap or overlap (dip faults), or they may be offset with overlap or gap (oblique faults).

Before base-leveling has been affected, but in an advanced stage of erosion, each layer of resistant rock, such as the trap, constitutes a ridge. The ridge

is repeated or offset, with or without overlap or gap, according to the relation of the direction of the fault plane to the dip and strike of the rock.

There is one condition under which an outcrop of the trap may be curved, even when the strata are not deformed. If the surface be in that stage of erosion where the trap constitutes a ridge, the outcrop of the trap will bend in the direction of dip wherever it is crossed by a valley; for here the ridge (outcrop) is lower than elsewhere, and lowering the surface of a dipping stratum always shifts its outcrop in the direction of dip.

All of the principles here set forth find illustration in the trap outcrops of the Newark series of Connecticut. The faults which are supposed to explain

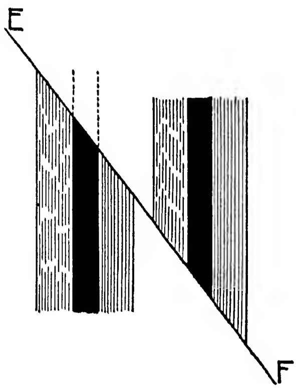


Fig. 333.

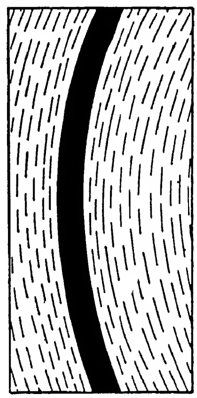


Fig. 334.

Fig. 333.—Illustrates the effect of oblique faulting on outcrops. The more the direction of the fault plane departs from the direction of dip, the greater the overlap (or if the opposite side had been the downthrow side, the greater the gap).

Fig. 334.—Diagram illustrating the effect of a gentle syncline, in beds of monoclinal structure, on outcrop, when the surface is plane.

the relations of the trap outcrops to one another have not all been seen, but the faulting is inferred from the relations of the trap sheets. Each outcrop of trap does not therefore mean a separate flow of lava. Three principal sheets of lava (all extrusive) seem to be represented by the many outcrops. Associated with these there are minor ridges of intrusive trap. The faulting in the Newark series of Connecticut has perhaps been most carefully worked out in the small isolated area near Pomperaug. Fig. 318 shows the outcrops of one bed of trap, and Fig. 319 that of another. In this small area, containing only about fifteen square miles, the number of faults is said to be more than 250.[1]

[1] Hobbs, 21st Ann. Rept. U. S. Geol. Surv., Pt. III.

The Triassic in the West.

The deposits of the western interior.[1]—When general sedimentation ceased in the eastern half of the United States near the close of the Paleozoic era, a tract along the Pacific coast probably remained beneath the sea, while another great area in the western interior, but partially and temporarily connected with the sea, became the site of varied sedimentation. Between the ocean on the west and this interior area of sedimentation, there seems to have been an elongate area of land which, including much of Mexico on the south, stretched north through western Arizona, eastern Nevada, western Utah, eastern Idaho, and western Montana, to British Columbia. In the United States, the interior area of sedimentation was chiefly between the 100th and the 113th meridians. Its southern limit, so far as now known, was not far from the southern boundary of the United States, while at the north it extended somewhat into Canada. This area of sedimentation is believed to have been cut off from the Gulf by a considerable land area in eastern Texas. If it had connection with the sea at all, as is very doubtful, it was probably slight, and with the Pacific Ocean north of the boundary of the United States. Into this interior area of sedimentation, which perhaps did not depart widely from the area of Permian sedimentation, detritus was borne from the surrounding lands. Some of the deposits were probably laid down subaërially by streams, some in fresh-water lakes, and some in bodies of salt water, as in the Permian period. The structure of some of the sandstone is such as to suggest strongly an eolian origin.

The deposits of the period are in large measure concealed by later beds, but are exposed at various points where the strata have been elevated, and the overlying beds removed by erosion. The most easterly outcrops of the system are found in Texas,[2] Indian Territory,[3] and South Dakota. The Triassic system may underlie the later formations west of these localities, and between them and the Rockies.

[1] There is some doubt about the age of most of the beds formerly referred to this system. The tendency of later study has been to refer more and more of them to the Permian. See references under Permian, and Hill, Physical Geography of the Texas Region, folio U. S. Geol. Surv.

[2] See last foot-note.

[3] Gould, Univ. of Kansas Quarterly.

Throughout most of this area, the Triassic beds are red, and in the absence of fossils, and of structural unconformity, are not readily differentiated from the Permian below.[1]

In Texas the beds generally regarded as Triassic underlie the "Staked plains" of the western part of the State, and outcrop along

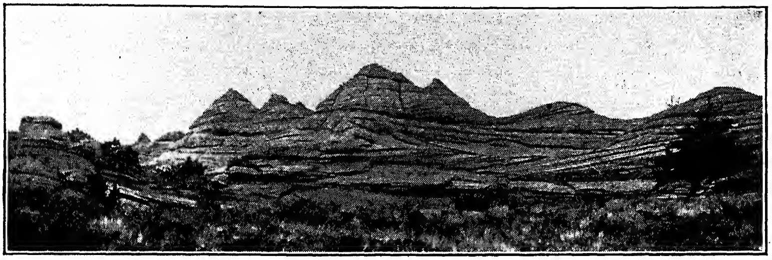


FIG. 335.—Triassic sandstone five miles south of Lander, Wyo., showing characteristic cross-bedding. (Branson.)

their eastern base. The deposits of this locality show that the water in which they were laid down was shallow and fresh, and the belief is that the sediments entered it from the east.[2]

In the Black Hills of South Dakota[3] unfossiliferous, gypsiferous beds (Spearfish) which are believed to be Triassic overlie the Permian conformably,[4] and underlie the Jurassic unconformably. The relations of the Triassic to the Permian and Carboniferous indicate that though the interruption of sedimentation at the close of the Paleozoic era was by no means complete in this part of the continent, the marine sedimentation of the earlier era gave place to salt-lake sedimentation in the later.

A series of nearly unfossiliferous strata, among which are many "Red beds" occupying the stratigraphical position of the Triassic system, outcrop interruptedly along the eastern base of the Rockies from British America to New Mexico. These beds are thin, and nearly everywhere contain more or less gypsum and sometimes salt. Occa-

[1] The Red Beds of Kansas, formerly thought to be Triassic in part, are probably all Permian (Williston). The opposite view is advocated by Prosser, University of Kansas Geol. Surv., Vol. II.

[2] Geol. Surv. of Texas, 1896, pp. 227–234.

[3] Newton, Geol. of the Black Hills, U. S. Geol. Surv.

[4] Darton, 21st Ann. Rept. U. S. Geol. Surv. Also Oelrichs and Edgemont, S. D.-Neb., New Castle, Wyo.-S. D., and Hartville, Wyo., folios, U. S. Geol. Surv.

sionally they contain fossil leaves of types which seem to ally the beds with the Trias of the east. In Wyoming, the Triassic beds, because of their high color and unique mode of erosion, are the most conspicuous formations of the State.[1] The Triassic beds of this region are not always readily distinguished from the Permian on the one hand, and from the Jurassic on the other. So difficult is the separation, that the Trias and Juras of this region are often grouped under the name Jura-Trias. Triassic beds have, however, been identified by means of fossils, in the Wind River region of Wyoming, where the fossil-bearing beds are 550 feet above the base of the Red Beds and 250 feet below the top.[2] The upper part of the Red Beds in this region is gypsiferous. Triassic beds have also been recognized in southern Wyoming by their vertebrate fossils.

Farther west, so far as the country has been carefully studied, Red beds have frequent representation among the surface rocks, but the outcrops are usually confined to narrow belts about the mountains where uplift and subsequent erosion have exposed the edges of the strata, or in valleys excavated through younger formations. Throughout all this region, red sandstones and shales make up a notable part of the Triassic system. Conglomerates are present locally, and gypsum is a common accompaniment of the clastic beds over most but not over all of the area.[3]

In southwestern Colorado, and in the adjacent part of New Mexico, some of the Triassic deposits seem to have been made in fresh water.[4] The fresh-water beds here and in Texas, and the salt-lake deposits over many other parts of the inland region, suggest that the Triassic sediments of different localities were laid down in separate basins. In much of this western interior region the undifferentiated Triassic and Permian rest conformably on the Carboniferous (Pennsylvanian), though occasionally, as in some parts of Wyoming, they overlap it and rest upon pre-Cambrian formations. Where non-fossiliferous Red

[1] Knight, Bull. 45, Wyoming Exp. Station, p. 133.

[2] Williston and Branson, unpublished data.

[3] For details, see the following folios of the U. S. Geol. Surv.: Ten Mile, Anthracite and Crested Butte, Telluride, Walsenburg, Pike's Peak, La Plata, and Pueblo, Colo.; Fort Benton, Little Belt, Livingston, and Three Forks, Mont.; Yellowstone Park, Wyo.; also Gilbert, 17th Ann. Rept. U. S. Geol. Surv., Pt. II, p. 560; and Knight, Bull. 45, Wyo. Exp. Station.

[4] Dolores formation, Telluride folio, U. S. Geol. Surv.

Beds rest on the Pennsylvanian conformably, at least the lower portion of the former should probably be assigned to the Permian. In southwestern Colorado and eastern Utah, the Trias rests unconformably on older, deformed, unfossiliferous Red Beds, and on strata of Pennsylvanian age, and perhaps overlaps even older formations.[1]

Thickness.—In the eastern part of the inland basin, the Triassic system is thin, sometimes no more than 100 feet. To the west it thickens, reaching to 2000 to 2500 feet in the Uinta Mountains, beyond which it again thins and becomes conglomeratic in western Utah. It is on the basis of these characteristics, as well as because of the absence of the system over western Utah and eastern Nevada, that the western limit of the interior basin is believed to have been in the longitude of Great Salt Lake. No general subdivisions of the system have been adopted for this region.

The Triassic system on the Pacific slope.[2]—In the latitude of Nevada, the Pacific seems to have extended eastward over the site of the Sierras to longitude 117° (approximately), as shown by the distribution of the marine Triassic strata. The shore line of the Pacific farther north has not been definitely located. It was probably irregular, and, in general, several degrees farther east than now, well up into British Columbia. Still farther north, between 55° and 60°, the sea is believed to have crossed the entire Cordilleran[3] belt, though this northern bay east of the Rockies was probably not connected freely with the areas of sedimentation in the western interior.

It is along the Pacific coast that the Triassic system in America has its greatest development. In the United States, the sediments of this part of the system appear to have been derived from the newly uplifted lands to the east. The published measurements assign the system the great thickness of 17,000 feet (maximum) in the West Humboldt range of Nevada,[4] where it rests on pre-Cambrian terranes. To

[1] Cross & Howe. The unconformity is seen near Ouray, in the Uncompahgre valley, and above Moab, on Grand River. Bull G. S. A., Vol XVI, p. 447.

[2] King, Geol. Surv. of the 40th Parallel, Vol. I. An account of the Triassic as far west as the Sierras in this latitude. See also the following folios, U. S. Geol. Surv: Bidwell Bar, Colfax, Downieville, Jackson, Lassen's Peak, Maryville, Mother Lode, Nevada City, Pyramid Peak, San Luis, Sonora, and Truckee, Cal., and Roseburg, Ore.

[3] Dawson, Science, March 15, 1901.

[4] King, loc. cit.

have supplied such a volume of sediment, the land to the east must have been high, or repeatedly renewed, to counterbalance the waste, unless the high measurement of thickness be due to oblique deposition.

In the western region, where the system has its greatest thickness, two principal divisions have been recognized, viz., the Koipeto below (4000 to 6000 feet thick), and the Star Peak above (10,000 feet). The lower of these series consists of siliceous and argillaceous beds, and the upper of sandstone, quartzite, and limestone. In the mountains, such as the West Humboldt range of Nevada, the system, especially the lower part of it, is highly metamorphic, and more or less affected by irruptive rocks.

Farther west, Triassic rocks, now upturned and eroded, are exposed near the summit of the Sierras [1] in northern California (Plumas County), and at various points northward to Alaska. Recently an extensive series of marine Triassic beds has been identified in the Eagle Creek Mountains of northeastern Oregon,[2] and in the Snake River canyon between Oregon and Idaho. In the northern part of the United States, the Triassic beds, if as wide-spread as the above occurrence suggests, are largely concealed by igneous rocks and by sedimentary beds of lesser age.[3] West of the Gold Range in British Columbia, Triassic formations (Nicola), largely igneous, are wide-spread and thick (13,500 feet). Locally, at least, the system is unconformable on the Carboniferous.[4] The igneous intrusions are thought to be largely submarine.[5] The Triassic is also known in Vancouver and Queen Charlotte Islands. Igneous formations of Triassic age are thought to be wide-spread in southeastern Alaska.[6]

Though most of Mexico appears to have been land during the Triassic era, there were within its area (Sonora) inclosed bodies of water, as in the United States. The estuary or inland-sea phase of the formation also appears in Central America.

The succession of faunas in the Trias of the Pacific coast indicates

[1] Geol. Surv. of California.

[2] Lindgren, Sci., Vol. XIII, N. S., 1901, p. 270.

[3] For details of the Trias (Jura-Trias) on the Pacific coast, see the following folios of the U. S. Geol. Surv.: Truckee, Bidwell Bar, Jackson, Lassen's Peak, Pyramid Peak, Mother Lode, and Sonora, Cal, and Roseburg, Ore.

[4] Dawson, Bull. Geol Soc. of Am., Vol. XII, p. 72.

[5] Dawson, Science, Mar. 15, 1901.

[6] Brooks, Bull. Geol. Soc. of Am., Vol. XIII, pp. 260–3.

that considerable changes in the physical geography of the northern Pacific were in progress during the period. In the early Trias, the waters of the Pacific coast seem to have been in such connection with those of the Indian and Arctic oceans that animal life was able to migrate back and forth[1] between these various regions, and the temperature seems to have allowed much wider migrations in latitude than are now common. In the Middle and Upper Trias there seems to have been faunal connection with the Mediterranean region, perhaps by way of the Indian Ocean.

Climatic Conditions.

The character of the conglomerates in some parts of the Triassic system has been made the basis of an argument for a cold climate during the Triassic period; but although the coarseness and lithologic character of the conglomerate are quite sufficient to suggest glaciation, they do not prove it, and the few fossils found do not bear out the suggestion.

Some of the peculiarities of the conglomerate might be explained if the climate were arid. In such climates, the expansion and contraction due to changes of temperature are so great as to be very effective in disrupting rock if its surface is not covered by soil or other débris. Under such circumstances, much coarse débris originates, largely of rock which is undecomposed. Violent storms (cloudbursts), which often characterize arid climates, might account for the transportation of débris from the place of its origin to the place of its deposition. For the formation of abundant débris in this way, steep slopes are needful, for gentle slopes and flats soon get a covering of soil or mantle rock which prevents the disruption of the rock beneath. If this were the origin of the coarse materials of the conglomerate, their rounding and wear would have to be attributed to the waves of the body of water in which deposition took place. The wide distribution of gypsum and salt in the Triassic system, not only of America but of Europe, is a positive argument for wide-spread aridity.

Close of the Trias.

Considerable geographic changes marked the close of the Triassic period in eastern North America, especially to the north, bringing

[1] Smith, Jour. Geol., Vol. III, p. 375.

the areas which had been the sites of deposition to a higher level, faulting the rocks, and affecting them by igneous intrusions. These changes were comparable in extent and importance to the changes which separate various systems of the Paleozoic series, but they were not of continental dimensions. The rocks of the next system are not represented north of Maryland, and perhaps nowhere in the Atlantic and Gulf plains. In the western part of the United States, there seem to have been no physical changes of great moment separating the Triassic from the Jurassic, and the sedimentary history of much of that part of the continent seems to have run an uninterrupted course from the beginning of the first of these periods to the later part of the second. The case may have been somewhat different north of the United States, for in British Columbia and in the adjacent islands, Triassic and older formations were upturned, deeply eroded, and again submerged before the beginning of the Cretaceous. The great igneous formations associated with the Trias of the northwest appear to have been made during the Triassic period; rather than at its close. The greatest body of igneous rock referred to this period, the great batholith of the Coast Range, is nearly 1000 miles long.[1]

Foreign Triassic.

Europe.

The Triassic formations of Europe are found in widely separated localities. The largest exposed area is in northeastern Russia, but the system is much better known in some other parts of the continent, especially in Germany and England. It is also known in most of the southern countries, though its outcropping areas are relatively small. In England, the system is unconformable on the Permian and older beds, thus showing that sedimentation was interrupted after the Permian period. On the continent, on the other hand, the Triassic system is generally conformable on the Permian.

The Triassic system of Europe has two somewhat distinct phases, known as the Triassic (largely non-marine) and the Alpine (marine) phases, repectively. The Triassic phase of the system is developed with more or less modification throughout the northern part of the

[1] Dawson, Geol. Soc. of Am., Vol. XII, p. 89, and Brooks, Geol. Soc. of Am., Vol. XIII, p. 260.

continent, while the Alpine phase characterizes the southern part. Physically, the non-marine phase of the system resembles the Permian of Europe, and the Permian and Triassic of the United States east of the Pacific slope.

In general, the Upper Trias is more wide-spread than the Lower,

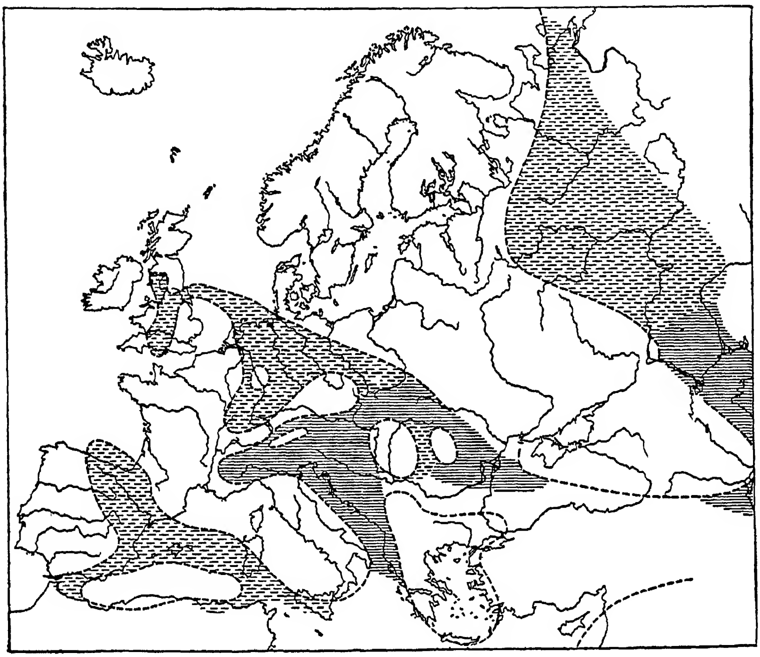


Fig. 336.—Sketch-map of Europe showing areas of sedimentation in the early part of the Triassic period. The broken lines represent areas of non-marine deposits; the full lines, areas of marine deposits. (After De Lapparent.)

especially in the southern part of the continent, and is marine over a wider area.

The following table gives the principal divisions recognized in Britain and Germany:

Britain.	Germany.
Rhætic, 150 ft. max.	Keuper, 820–2000 ft.
Upper Trias., 3250 ft. max.	Muschelkalk, 820–1100 ft.
Lower Trias., 2000 ft. max.	Bunter, 650–1800 ft.

Germany.—In Germany, where the Triassic phase of the system was first exhaustively studied, and where it has its typical develop-

ment, it is made up of three principal divisions. The oldest (*Bunter*) and youngest (*Keuper*) divisions consist of beds of fragmental rock, including conglomerates, sandstones, and shales, separated by a formation (*Muschelkalk*) of limestone. The oldest of these formations was deposited chiefly in lakes, inland seas, and on the dry land, as shown by the fossils, the beds of salt and gypsum, and the dune structure of the sandstone.[1] There are in some places cubes of sandstone, the sand of which appears to have been originally included in crystals of salt, as that mineral was precipitated from solution in inclosed bodies of water. Subsequently the salt was dissolved, but replaced by other cementing matter which preserved the cubes of sandstone. Toward the upper part of the formation, thin beds of marine origin are locally intercalated with those of non-marine origin, showing that changes in the relation of land and water were in progress, and that the sea gained on the land to some extent toward the close of the epoch. Tracks of land reptiles are sometimes found on the layers of shale and sandstone, showing that they were deposited on land or in water sufficiently shallow to allow terrestrial animals to wade in it. The tracks sometimes occur in layers which had been cracked by drying at the time the tracks were made. This shows that the mud-beds over which the reptiles walked were sometimes dry, and that for periods sufficiently long to let the cracks develop. The areas where these phenomena occur may have been under water during wet seasons, and dry at other times.

The tracts where this formation comes to the surface are, on the whole, not fertile, and have been allowed to remain in forests extensively. So true is this, that the Bunter sandstone may be said to be the "forest formation" of western Germany. The name (Bunter) has reference to the brilliant colors displayed by the formation. Red predominates, but other colors are not absent. The Bunter sandstone of the Eifel carries galena in small grains and lumps, and the Romans mined it.[2]

The second formation, the *Muschelkalk*, shows that the encroachment of the sea recorded by the upper part of the preceding formation had gone so far that the ocean held sway over much of the area where

[1] Kayser, Geologische Formationskunde, p. 330.
[2] Ibid , p. 283.

it had been absent formerly. The Muschelkalk fauna has been thought to indicate that the sea in which it lived was not the open ocean, but rather a body of water comparable to the Black Sea or the Baltic.[1] As the name indicates, limestone makes up the larger part of the formation.

The third formation, the *Keuper*, resembles the first, and, like it, is marine in its upper portion, and is followed by the marine beds of

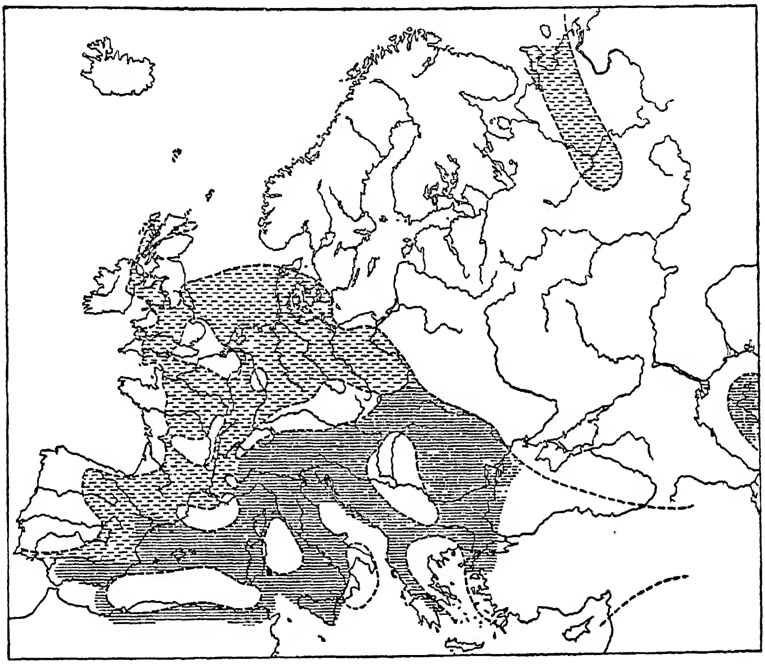


FIG. 337.—Sketch-map of Europe, indicating the areas of sedimentation during the late Triassic. The broken lines represent areas of non-marine deposition; the full lines, areas of marine deposits. (After De Lapparent.)

the Jurassic period. The Keuper contains a little coal (not workable), a common accompaniment of shallow-water and marsh formations.

England.—The chief point of difference between the Trias of Germany and that of England lies in the fact that the marine member of the former is absent from the latter. Otherwise the system corresponds in the two countries, so far as general characters are concerned. The absence of the marine division from the system in

[1] Kayser, op. cit., p. 286.

England shows that the sea which overspread Germany did not cover England, and the conformity of the Upper Trias with the Lower in the latter country leads to the inference that the time equivalent of the *Muschelkalk* is included in one or both of these divisions. The uppermost (marine) division of the system in England (the Rhætic) corresponds in a general way with the upper part of the Keuper (also marine) in Germany.

In the two countries the Triassic system has the following points in common: (1) The dominant color is red; in England, indeed, the system is commonly known as the New Red Sandstone system, though the Permian was formerly included under this term; (2) in both countries the formations are poor in fossils; (3) in both, gypsum and salt are present. In England the salt occurs in workable, lens-shaped beds, sometimes 200 or 300 feet in thickness. The gypsum, in the white amorphous form of alabaster, also occurs in workable quantity in some parts of England. (4) In both countries, the strata bear abundant marks of shallow-water or subaërial origin, such as footprints of land animals, cross-bedding, and rapid changes laterally in the composition of the beds.

The Upper Trias of England is rather remarkable for containing a large amount of dolomitic conglomerate. This, as will be remembered, is locally one of the characteristics of the Newark series in the eastern part of the United States. In England, however, the origin of the conglomerate presents no serious problem, for it lies against the limestone cliffs from which its materials were derived.

Sweden and Russia.—In southern Sweden, where the Trias has slight representation, it contains coal, showing that the same general conditions (shallow lakes, marshes, etc.) prevailed in the north as in the rest of western Europe. The Trias of Sweden was probably once continuous with that of Germany, and may still be, for borings have shown that it underlies various parts of the North German lowland. The Trias of most of Russia consists of highly-colored beds (mainly red) which are poor in fossils. They appear to belong to the non-marine phase of the system. No contemporaneous igneous rocks are known in the Triassic phase of the system.

The character and the distribution of the Triassic beds of northern and western Europe have led to the inference that the Triassic beds of Britain were accumulated in great inland basins which

"covered a large part of England, and seem to have extended north into southern Scotland and across the area of the Irish Sea into the northeast coast of Ireland. It is possible also that the same sea stretched across what is now the English Channel into northern France. Another lake is indicated by the red sandstones of Elgin (northeastern Scotland). The lands surrounding these lakes were clothed with cypress like evergreens, and their shores were frequented by the labyrinthodonts and various reptiles—the highest forms of vertebrate life being represented by small marsupials. The briny waters were unfavorable to life, and we have consequently but little trace of any aquatic fauna. . . . Eventually the lacustrine areas became largely silted up, and then subsidence of the land took place, so that the sea invaded the area and occupied some of the shallow depressions. In these marine areas the Rhætic deposits accumulated.

"On the continent, the evidence supplied by the German Trias shows that during a large part of the period an extensive inland sea extended westwards from Thüringerwald across the Vosges into France, and stretched northwards from the confines of Switzerland over what are now the low grounds of Holland and northern Germany. In this ancient sea, the Harz Mountains formed a rocky island. In the earlier stages of the period the conditions seem to have been much the same as in the English area, but the thick Muschelkalk, with its numerous marine forms, seems to indicate an influx of water from the open sea. Afterwards, however, this connection was closed, and the subsequent accumulations point to an increasing salinity, during which depositions of gypsum, rock-salt, etc., took place, while the marine fauna disappeared. Towards the close of the period, after the great lake had been largely silted up, a partial influx of the sea took place, when deposits containing a fauna comparable to that of the English Rhætic were laid down in some areas."[1]

This citation perhaps fails to recognize adequately the probable subaërial origin of some parts of the Triassic system.

Southern Europe.—In contrast with the Triassic phase of the system, the alpine or marine phase, which has its best development in the eastern and southern Alps, is made up of thick beds of limestone (often dolomitic), alternating with thinner beds of clastic rock. The limestone and dolomite are much more resistant than the associated shales, and as a result, erosion has developed a striking topography at several points in the Triassic terranes of the southern Alps —a topography so striking that the localities where it is seen have become the objective point of travel, not only for geologists, but for lovers of wild and picturesque scenery. In these regions the dolomite (limestone) stands up in bare, bold-faced walls, peaks, and towers,

[1] James Geikie, Outlines of Geology, pp. 311–312.

surrounded and separated by valleys and passes clothed with abundant vegetation. The decay of the projecting limestone leaves little soil behind, since most of the rock is soluble, and the little which is formed is promptly carried away by wind and rain.

In the eastern Alpine region there are large and more or less individual bodies or "reefs" of dolomite, and sometimes of limestone, which possesses exceptional characteristics. They are essentially without stratification, are poor in fossils, have steep slopes, and a superficial bedding concentric with the surface. As the steep slopes suggest, these reefs wedge out rapidly on some or all sides. These bodies of dolomite (or limestone) attain great thicknesses, and are associated sometimes with thinner beds of stratified limestone or dolomite of a composition like their own, and sometimes with beds of clastic rock which fit up against them on some or all sides. From the reefs, there are often projections of dolomite extending out into the clay-beds surrounding.

In spite of the difficulties involved in the explanation, it is very generally believed that the so-called reefs are really such, and probably of coral origin. The absence of abundant fossil corals in them seems at first a difficulty; but corals are the most abundant fossils found, and the absence of recognizable coral structure in the body of some modern coral reefs is well known. Coral is one of the most soluble forms of $CaCO_3$, and is therefore more readily subject to change than most other organic deposits of this substance. Coral reefs are known to possess the superficial concentric stratification which characterizes these reefs, and to possess similar lateral projections. On the whole, the structure of the dolomite reefs seems more readily explained on the coral reef hypothesis than on any other. In the making of the limestone of the alpine phases of the system, marine algæ appear to have played an important part, and even the reefs have been ascribed to them.

The Trias of the Italian Alps is the source of the Carrara marble. The Trias of the western Alps is largely non-marine. In some parts of Switzerland, the Upper Trias contains coal, and contemporaneous igneous rocks enter into the same division of the system.

The marine phase of the system shows that the physical conditions which obtained in southern Europe, where there was an open sea, were notably unlike those of western and northwestern parts of the continent

at the same time. This is in keeping with the physical conditions which existed in the continent almost uninterruptedly after the beginning of the Paleozoic era. Near the close of the Trias (Rhætic), the differences between the eastern and southern Alps on the one hand, and northern and western Europe on the other, became much less distinctly marked.

The marine phase of the system reaches its greatest thickness (about 13,000 feet) in the southern Alps, where the deposits are thought to have been made in a great geosyncline, and the beds were subsequently made into mountains as in the case of the Appalachians.

The non-marine formations of red color so characteristic of the system both in North America and Europe afford another striking inter-continental analogy.

Asia.—The marine phase of the system found at various points south of the Alps is continued eastward through the Carpathian and Balkan Mountains to Asia, where it is found in Asia Minor, in the Himalayas, the Salt Range, and still farther east. The Trias of Afghanistan is partly non-marine, and contains some coal. The Trias of the Deccan also is non-marine, and constitutes the upper part of the great Gondwána system, of which the lower parts (Talchir, etc.,) are Carboniferous or Permian.

The Marine Trias is also found in the high latitudes of Asia and Europe, including Japan, eastern Siberia, and numerous islands north of Eurasia (Spitzbergen, Bear Island, the New Siberian Islands, etc.).

In Asia the Trias is generally conformable above the Permian, and beneath the Jurassic. The relations of the Permian in India suggest that the great changes marking the transition from the Paleozoic to the Mesozoic occurred at the close of the Carboniferous, or during the Permian, rather than at the close of the latter.

South America.—In South America no marine deposits of Triassic age are known east of the Andes, from which it is inferred that this part of the continent was out of the sea. Non-marine Triassic beds are known in Argentina and Chili, where they are coal-bearing.[1] Marine Triassic beds are known at various points in the Andes, in such positions as to show that the site of parts of this great system of mountains was at this time beneath the sea.

[1] Kayser, op. cit., p. 308.

Africa and Australia.—The Triassic system seems to be present in South Africa (Karoo sandstone), in Australia (Hawkesbury sandstone of New South Wales), and in New Zealand and New Caledonia. In New Zealand, it contains coarse conglomerate.

General provinces.—Reviewing the Triassic system of all countries, Kayser[1] recognizes five provinces of the marine part of the system. There are (1) the Mediterranean province, (2) the southern Asiatic province, (3) the Paleo-arctic province, (4) the American (western North and South America) province, and (5) the Australian province. This grouping is based largely on faunal characteristics. The first and second provinces have some species and many genera in common, while the fourth has some likeness with the first, second, and third.

The Life of the Triassic Period.

Those remarkable physical conditions that had dominated the land and impoverished its fauna and flora in the Permian period still held sway during the earlier part of the Triassic. In their general biological aspects, as in their physical, the two periods were akin, if not really parts of one great land period. Toward the close of the Triassic there was a pronounced change, attended by a physical and biological transition toward the Jurassic stage, in which lower levels and greater sea encroachment prevailed, with corresponding life phases. Nearly all that is known of North American Triassic life belongs to this later portion of the period.

The Plant Life.

The record of the vegetation is very imperfect. The vegetation was probably scant in reality, for broad saline basins and arid tracts imply conditions inhospitable to plant life. An environment that could give rise so generally to coarse red sandstones and conglomerates—even limestone conglomerates—could not well be congenial to luxuriant vegetation.

The dominance of the gymnosperms.—The Triassic was distinctly an age of gymnosperms the world over; the supremacy of the pteridophytes had ceased, though ferns, true to their persistent nature, still held an important place, and the equisetales were a more vital

[1] Geologische Formationskunde, pp. 327–329.

factor than now. The great lycopods were almost gone, the last of the sigillarias being among the lingering representatives. Among the gymnosperms, the cordaites were already far down their decline towards extinction, but conifers of the types that had come in during the Permian, and kindred new ones, were prominent, while the cycadean group was still in a stage of deployment and occupied the central place of interest. Very much as the ferns in the Carboniferous period were deployed into transition forms (*Cycadofilices*), so now the cycadeans had a divergent branch, the *Bennettitales*, which until recently were classed simply as cycads. The cycads have heretofore been regarded as embracing three groups, the *Cycadeæ*, now typified by the *Cycas* of the eastern hemisphere, the *Zamieæ* similarly typified by the living *Zamia* of the western hemisphere, and the *Bennettiteæ*, a wholly extinct family supposed to be true ancestral cycads; but recent investigations have shown that the last differ from the others so much in structure and mode of fruiting as to require their recognition as a divergent type. While this divergence is universally recognized, some paleobotanists conservatively leave the group in the class *Cycadales*, under the name *Bennettiteæ*, while others make it a separate class, *Bennettitales*.[1] It is at any rate cycadean in the broad sense of the term.

Besides many structural peculiarities which cannot be noted here, the seed of the *Bennettitales* had certain angiospermous features. Suggestive as this fact is, it is not to be inferred that the *Bennettitales* were the ancestors of the angiosperms, for this is regarded as improbable. In many cases the imperfect relics of Triassic species do not afford the criteria for distinguishing between the *Bennettitales* and the *Cycadales*, and such forms can only be spoken of as cycadeans. It is probable that the majority of the known species were bennettitalian, but the true cycad branch was probably represented. Among the genera referable to the group were *Zamites* (Fig. 338, *e*, *f*), *Otozamites* (Fig. 338, *i*), *Podozamites* (Fig. 338, *j*), *Pterophyllum*, *Ctenophyllum*, and *Cycadeomyelon*, the last, at least, identified as bennettitalian. The Triassic conifers bore the scrawny aspect of the walchias and voltzias of the Permian. They deployed into many new genera of like types, such as *Palissya* (Fig. 338, *a*), *Brachyphyllum* (Fig. 338, *c*),

[1] Scott, Studies in Fossil Botany, 1900, pp. 445–475; Coulter, Seed Plants, 1901, pp. 142–150; Ward, Older Mesozoic Floras of U. S., 20th Ann. Rep. U. S. Geol. Surv., II, pp. 242–248, 1898–1899.

Cheirolepis (Fig. 338, *b*), *Albertia*, and *Ullmania*. The ginkgos were represented by *Baiera*. It does not appear from the record that any of these gymnosperms were especially large, but on the contrary rather dwarfish, the conifers bearing the aspects now found on sandy barrens and arid tracts. The calamites had given place to true equiseta, which were represented by forms that were gigantic in comparison with modern types. In the far east and in the southern hemisphere, the *Glossopteris* and its allies constituted a marked feature of a flora whose general aspect was much like that of the preceding Permian in that quarter. The Triassic floras of Europe and America, so far as known, were much alike and bore a scrawny pauperitic aspect that reflected the hostile conditions against which they struggled, conditions for which the stunted conifers of to-day stand as representatives.

In the closing stages of the period, the Rhætic epoch and its equivalents, there seems to have been much amelioration of the previous hostile conditions and a much ampler development of the flora. The larger part of the known American fossils belong to this stage. In favored portions of the Newark series from Connecticut to North Carolina, plant remains occur, and in the coal-beds of the latter state and of Virginia, the flora is more amply represented. The Richmond coal-beds are regarded by Fontaine[1] as the product of marsh vegetation accumulating where it grew, while the Carolinian deposit shows more evidence of inwash, and represents the vegetation of the adjacent country. The habitats represented by the fossils of the more northerly states are less clear, but it is doubtful whether any represent the typical upland-inland vegetation.[2] The coal-beds of Virginia contain immense numbers of equiseta and ferns, but almost no conifers and but few cycadeans; the North Carolina deposits, comparatively few ferns, but many conifers and cycadeans. As this distribution implies that the conifers were not marsh plants, the pseudoxerophytic peculiarities of such plants cannot be appealed to in explanation of the markedly xerophytic aspect of the Triassic conifers, as was done in the case

[1] Mon. VI, U. S. Geol. Surv., 1883.

[2] The older Mesozoic plants of this region have been made the subject of a special memoir by Fontaine, Mon. VI, U. S. Geol. Surv., 1883; those of New Jersey and Connecticut by Newberry, Mon. XIV, U. S. Geol. Surv.; and all have been summarized by Ward, Twentieth Ann. Rept. U. S. Geol. Surv., Pt. II, 1898–99, in which there is reference to all previous writers, and quotations from the valuable paper of Wanner.

of the Carboniferous trees. The group figure (Fig. 338) embraces characteristic forms from the Newark formation. A few plant fossils have been recovered from New Mexico, Arizona, and California (Taylors-

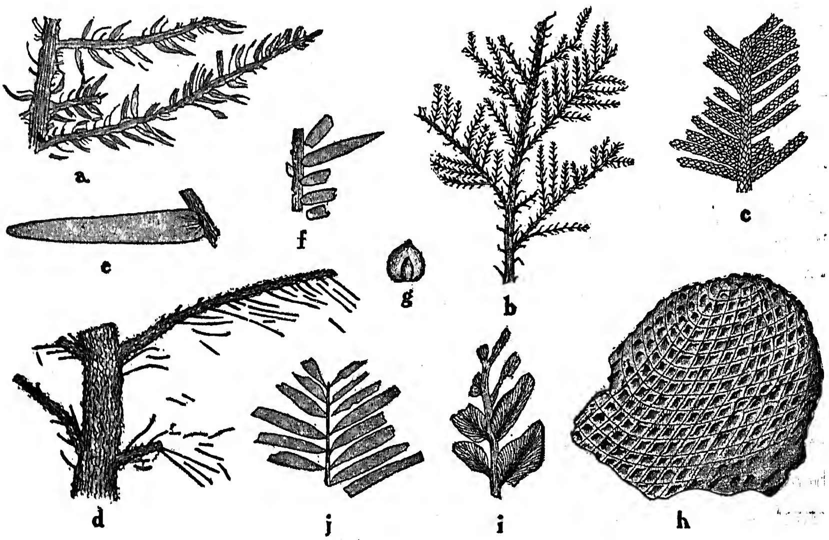


FIG. 338.—A GROUP OF TRIASSIC GYMNOSPERMS FROM THE ATLANTIC COAST. CONIFERS: *a*, *Palissya sphenolepis* Brong., a form closely allied to *Walchia*; *b*, *Cheirolepis muensteri* Schimp.; *c*, *Brachyphyllum yorkense* Font.; *d*, *Schizolepis liaso-keuperinus* Braun. CYCADEANS: *e*, *Zamites yorkensis* Font.; *f*, *Zamites pennsylvanicus* Font.; *g*, *Cycadeospermum wanneri* Font.; *h*, *Cycadeoida emmonsi* Font.; *i*, *Otozamites carolinensis* Font.; *j*, *Podozamites tenuistriatus* Font.

ville). Limited coal deposits were formed in Germany and Scandinavia, from the latter of which 150 species of plants have been recovered.[1]

The Land Animals.

All evidences point to complete continuity between the Permian and Triassic land animals. The vicissitudes of shifting aridity and other changeable conditions seem to have markedly affected both periods, but not to have put barriers between them; rather to have made adaptation to the one a fitting preparation for continued evolution in the other. The record probably does not show, however, the land animals most affected by the vicissitudes of the Permian and Triassic climates, but rather those which frequented the water-

[1] For general treatment of Triassic plants see Zeiler's and Potonie's treatises, previously referred to.

borders and the adjacent lowlands where alone relics were usually preserved by sedimentation.

Though the amphibians had lost the foremost place in the Permian, they still formed a notable element in the European and American Triassic faunas. More than twenty-two genera have been described, all belonging to the *Temnospondyli* and *Stereospondyli*, or true labyrinthodonts. During the period, however, they entered upon a rapid decline, and by its close had ceased to be a prominent feature of the land-life, a decline from which they have never recovered. Ancestors of the whole tribe of terrestrial vertebrates, they soon became its most insignificant representatives. None of the modern amphibians had yet appeared.

The strange ancestral reptiles rapidly evolved into higher forms. The branch with the mammalian strain (*Synapsida*) seems to have been left far behind by the more distinctively reptilian branch (*Diapsida*). The latter developed prodigiously in the closing stages of the period, when the conditions were ameliorated, and vegetation began again to flourish and furnish a better basis for animal life. Every chief group of reptiles had its representatives before the close of the

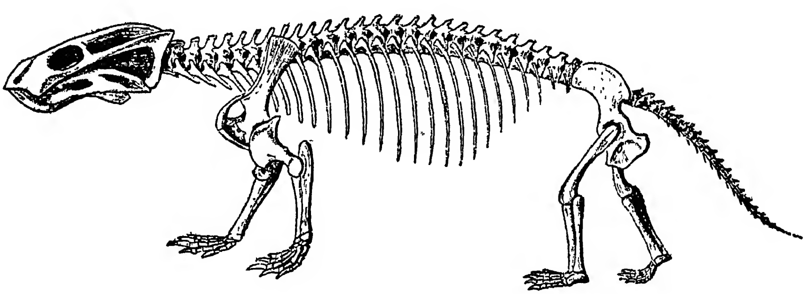


FIG. 339.—*Oudenodon trigoniceps*. An anamodont (or Dicynodont) from the Karoo formation of South Africa, so similar to forms of the Trias in Wyoming as to be distinguished from them with difficulty. (After Broom.)

period, *Rhynchocephalia* (including the *Proterosauria* and *Gnathosauria*), *Crocodilia* (including *Phytosauria*), *Thalattosauria*, *Ichthyosauria*, *Squamata*, *Dinosauria* and *Pterosauria*, of the diapsidan group, and *Theromorpha* (*Anomodontia*), *Chelonia* and *Sauropterygia* (*Nothosauria* and *Plesiosauria*) of the synapsidan group. As the reverse side of this remarkable development, some of the older types, as *Proterosauria*, *Phytosauria*, *Theromorpha* and *Nothosauria*, disappeared with

the period. Some of the orders came into the record so near the close of the period that they play little part in its faunal history. Such are the true crocodilians, the flying saurians (*Pterosauria*) and the scaled reptiles (*Squamata*), which include the lizards, dolichosaurs, pythonomorphs and snakes. A true lizard has recently been reported by Broom from South Africa.

The rise of the dinosaurs.—A foremost feature was the advent and rapid evolution of the reigning reptilian dynasty of the Mesozoic. Arising probably from some of the more primitive forms of the rhynchocephalians, the dinosaurs (terrible saurians) were at first generalized and rhynchocephalian in aspect, but later became more specialized and diverged widely. While some were small and delicate in structure, the more noted forms were gigantic and ungainly to an extreme degree, especially the herbivores of the following periods, when the deployment of the order was at its climax. Only the carnivorous forms (*Theropoda*) are known in the Trias, and these were not usually as yet gigantic. Their general form is indicated by the partially restored skeleton shown in Fig 340. The strong development of the hinder parts, the relative weakness of the fore limbs, and the kangaroo-like attitude, are the most obvious features. The bones of these upright-walking forms were hollow, and certain other structural features resembled those of birds, among them the reduction of the functional toes of the hind feet to four, with one of these much shorter than the others so that their tracks were often three-toed, like the famous "bird tracks" of the Connecticut valley. As the bones of the *Anchisaurus* and allied genera are the only relics found with these "bird tracks," it is supposed that they and their relatives were responsible for them, which is made the more probable by the occasional imprint of the fourth toe and of the fore foot. Most of the bird-like characters of the dinosaurs are more probably due to parallel evolution than to any immediate ancestral relationship to birds; more remotely, birds and dinosaurs probably arose from a common stock. The dinosaurs will claim much further attention in the following periods. Even as early as the Triassic, they had a wide and significant distribution, appearing in the Rocky Mountains, North Carolina, Pennsylvania, Connecticut, Prince Edwards Island, England, Scotland, France, Germany, India, and South Africa.

The advanced differentiation of the chelonians.—The turtle tribe

was represented in the record by *Proganochelys* (*Psammochelys*), a highly specialized form belonging to the *Pleurodira*, from the Upper Trias of Europe, as well as by others (*Chelyzoon*) of true cryptodiran

FIG. 340.—A Triassic dinosaur of the Connecticut valley, *Anchisaurus colurus*, restored by Marsh, one-thirtieth of natural size.

affinities from the middle Trias,[1] indicating, by their divergence and specialization, a much earlier origin of the chelonian order.

The advent of the non-placental mammals.—Of peculiar interest is the appearance of early forms of non-placental mammals. They were small, and so primitive in type, that it is not altogether certain that they were not mammal-like theromorphs. They are regarded, however, as prototherian mammals, allied to the monotremes and marsupials. The remains are fragmentary, teeth being the most significant portions preserved. These show relations to the theriodonts, and perhaps point to them as the source of descent, though this is far from certain. Two genera are recognized in America

[1] Recently described by von Huene.

(*Dromotherium* and *Microconodon*) and one in Europe (*Microlestes*). This early appearance of the mammals, while yet the reptiles were strongly ascendant, doubtless indicates a very early ancestry, suggesting that perhaps the mammalian divergence began while yet their ancestors were stegocephalians, as some believe, or in the very early stages of the reptilian evolution in connection with the theromorphian development, as others believe. In view of the mammalian dominance of the recent ages, it is not a little instructive to note that the non-placentals developed very slowly and feebly in America and Europe during the whole Mesozoic era. Question has even been raised whether the placental mammals are the descendants of these Mesozoic non-placentals, with the suggestion that perhaps they had an independent and equally early origin, a question on which future studies in Africa, where the theromorphs had their strongest early development, is likely to throw light.

The reptiles go down to sea.—Both wings of the reptilian horde sent delegations to sea before the close of the period, the thalattosaurians and ichthyosaurians representing the more declaredly reptilian line, and the sauropterygians (plesiosaurians) representing the mammalian branch. This similarity of movement and of adaptation has associated the ichthyosaurs and plesiosaurs in geological thought, though they are not close allies biologically. It is not difficult to find good reasons for this movement to the sea. Besides the inevitable tendency of every masterful race to invade all accessible realms, the renewed extension of the sea that set in during the Triassic period and became pronounced before its close, especially invited this; for the shallow waters, creeping out upon the land, with their now prolific life, set tempting morsels before the voracious reptiles, on the one hand, while on the other, the reduction of the land area and the restriction of their feeding-grounds, intensified by their own multiplication, forced a resort to the sea.

The sauropterygians seem to have been the leaders in this movement and to have become almost at once lords of the sea, and to have preyed upon the previous rulers, the fishes. The nothosaurs were the earlier and more primitive type of the sauropterygians and reached their climax and closed their career within the period; but true plesiosaurs were present. The accompanying restoration of the skeleton of *Lariosaurus*, a genus confined to the Trias, illustrates by its well-

developed limbs how certainly it had been a land form. In later forms, the limbs were modified into paddles, and all adaptation to locomotion on land was lost. The ancestral affinities of the order are with the anomodonts. The eighteen Triassic genera that have already been

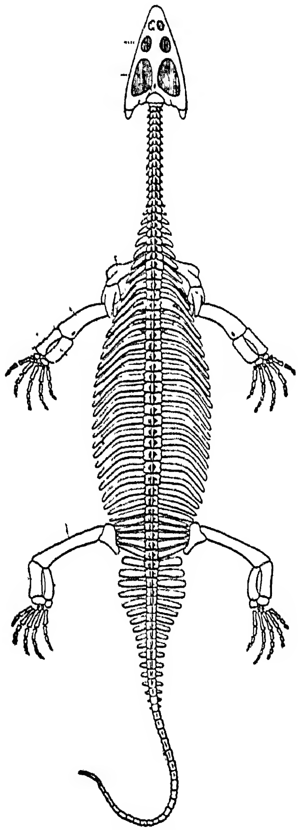


FIG. 341.

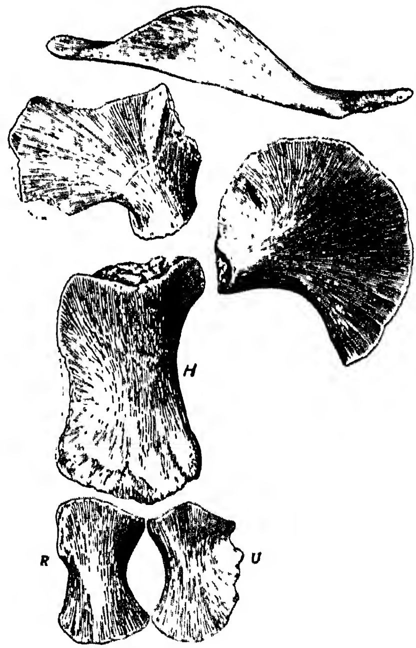


FIG. 342.

FIG. 341.—A Triassic sauropterygian, *Lariosaurus balsami*, restored; about one-tenth natural size; from the Muschelkalk, Lombardy, Italy. (After Woodward.)
FIG. 342.—A primitive ichthyosaurian limb from the Middle Triassic of Nevada, showing the elongation of the arm bones (*H*, humerus; *R*, radius; *U*, ulna) characteristic of land animals. The structure is in contrast with that of the later ichthyosaurs. (After Merriam.)

described show the great progress in evolution the order had made before the close of the period.

Numerous primitive forms of ichthyopterygians (fish-limbed reptiles) have recently been discovered by Merriam in the Trias of Cali-

fornia. These, the *Thalattosauria*[1] (Fig. 343), were a strange group of true marine reptiles, probable descendants of some early rhynchocephalian-like reptile. The skull, though of ichthyosaurian aspect, differed widely from the ichthyosaurian skull in structure, and was remarkable for the possession of numerous teeth on the palate. The group apparently soon became extinct, without descendants. The Thalattosauria were less remotely removed from their ancestors than the well-known ichthyosaurs of the Jurassic period, whose limbs had

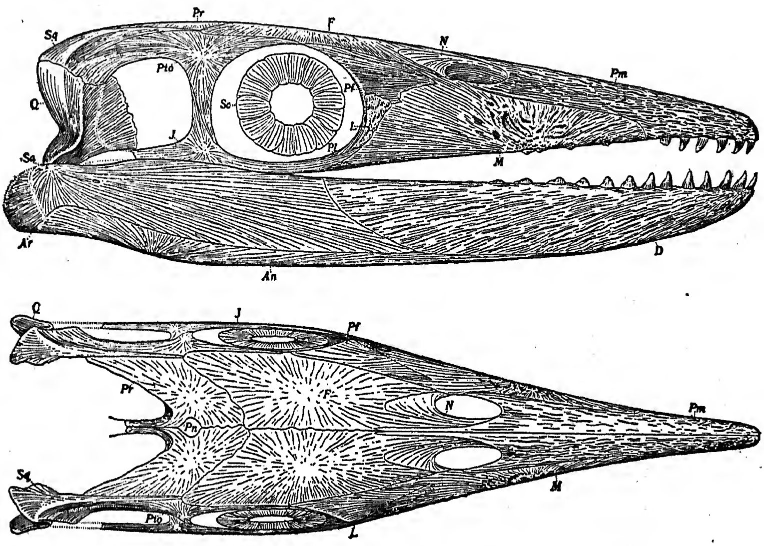


FIG. 343.—Skull of *Thalattosaurus alexandræ* (side and top), about $\frac{2}{7}$ natural size. (After Merriam.)

been, for the most part, converted into short broad flipper-like paddles. In the newly-discovered Triassic forms the limb-bones were longer (Fig. 342), and shaped more like those of the walking reptiles; the hind limbs were often as large as the forward ones, while in other characters they were more primitive.

In many respects the Triassic land life, both plant and animal would fall into its more natural relations if its evolutions in the latter part of the period were united with those of the Jurassic. While the early Trias was closely akin, physically and biologically, to the Permian, the later part was little more than the initial phase of the Jurassic.

[1] Recently described by Merriam.

Defined as it now is, the Triassic was a period of great transitions, in which many types were inaugurated, but a few only were carried to their characteristic developments.

The Marine Life.

The physical description has made it clear that the withdrawal of the sea which restricted the marine life of the Permian was continued into the Trias, during which it reached its climax, at least in North America. There was then a very general emergence of what is now land, and probably also of some tracts now submerged. The marine life of the shallow-water type was therefore not only greatly reduced, but because it occupied border tracts now buried, such record as it made is mainly concealed from present examination; in other words, there was not only less life, but we know less relatively about what there was. This was not equally true of other continents, although measurably true of all, so far as present knowledge extends. To follow the continuity of the shallow-water marine life, it is necessary to bring together evidence from different continents. The question of supreme interest is the mode by which the epicontinental sea life, crowded to a minimum between the land and the deep sea, maintained its continuity, transformed its species, and, emerging at length, re-peopled the shallow waters when they again spread out upon the continental platform in the closing stages of the Trias and in the Jura.

When the sea readvanced on the North American continent, it was primarily from the Pacific border, but was attended by incursions along the Mackenzie Valley and from the Gulf of Mexico. It was not till long after that an advance from the Atlantic made an accessible record. It is not clear that the sea ever completely withdrew from the present land area on the Pacific border, but the fossils so far recovered do not give clear evidence that there was there at all times a harbor of refuge, or an embayment of shoal water of sufficient area to develop, during the retreat of the sea, a definite provincial fauna which subsequently spread with the advancing seas and made itself felt as a pronounced faunal unit. Rather does the evidence seem to point to a coastal tract merely, in which a restricted fauna lived on and developed new species which migrated subsequently as individuals, rather than as a faunal assemblage.

The transition tracts.—It was otherwise on the eastern continent.

It has been noted that the sea during the Permian period withdrew from the northwestern portions of Europe, but lingered in the south about the Mediterranean, and in the east in Russia. At the climax of the retreat, the sea seems to have been confined more narrowly to the Mediterranean region. In Asia, the sea had lingered in Turkestan and northwestern India (Salt Range and Himalayas). In the latter region the sea seems even to have advanced, for there is an unconformity below the Permian, and, by retaining the ground thus acquired till after the opening of Mesozoic time, afforded a theater for the great transition from the Paleozoic to the Mesozoic. It is inferred from the appearance of a specialized marine fauna in Siberia early in the Triassic period, that the sea lingered on the continental platform somewhere in that quarter through the Permian and into the Mesozoic, and that this also was an originating tract of faunas. These three regions, the Mediterranean, the Himalayan and the Siberian, are the best known tracts into which the shallow-water marine life of the Paleozoic retreated and underwent transformation into the early provincial faunas of the Mesozoic. It is quite certain that there was at least one other area where important faunal reorganization took place, for a notable fauna suddenly appeared in the Middle Triassic, which does not seem to have originated in any of these three districts. Very likely there were still others.

The transition faunas.—In each of these areas an important remnant of Paleozoic sea life seems to have persisted and to have undergone a radical and perhaps rather rapid evolution, such as might be anticipated from the crowding of the great faunas of the Carboniferous times into such limited areas, relieved only by the narrow coast-border tracts and incidental dependencies. From these areas the new faunas spread forth as the sea again extended itself upon the land.

In the Indian basin there is a nearly continuous record of the transition from Paleozoic to Mesozoic marine life. Beds containing the characteristic life of the Permian, the *Productus* fauna, are immediately and conformably followed by beds containing the ammonite *Otoceras*, and other forms of characteristic Mesozoic life. In the *Productus* beds below the dividing horizon there are forms foreshadowing the Mesozoic types, and in the beds above that horizon there are forms of the Permian type that lived on past the dividing datum, and com-

mingled with the Mesozoic forms; in other words, there was a gradation of the Paleozoic forms into the Mesozoic.

The transition fauna appears to have been richer in this region than that in the Mediterranean basin. In the Yakutic stage, a division of the early Trias, there are now known to have been two hundred and twelve species of cephalopods in the Indian province, against twenty-five known at the corresponding stage in the Mediterranean province (J. Perrin Smith), which is the more notable since the latter has been much more thoroughly studied. Because of the superior richness, as well as the close continuity of the life of the Himalayan province, it is entitled to be styled the cradle of the Mesozoic fauna *par excellence*. More strictly, however, it was the cradle of a leading provincial fauna of the early Mesozoic only. The Mediterranean province soon developed a vigorous rival fauna which deployed so strongly in the later Trias, that it is regarded as the more representative fauna.

Concerning the early stages of the Siberian fauna very little is known; but its peculiarities, as they were better revealed in a later stage of the early Trias, leave little doubt of its independence of origin. Of other transition provinces still less is known. It is significant, however, that an important group of ammonites (*Tropitidæ*) appeared in the Eurasian provinces suddenly and in great force, toward the middle of the Triassic. As these ammonites had no immediate ancestry within these regions, it is inferred that they were immigrants from some other originating tract, and this tract will doubtless be discovered in time as the study of other regions progresses.

In a minor way, the general coast tract of all the continents, though narrow, was doubtless the originating tract of some species, and perhaps of minor faunas.

It is scarcely necessary to remark that the pelagic and abysmal life of the main ocean is not embraced in this review, and is practically unknown.

General nature of the faunal change.—In nearly all the Paleozoic faunas, the brachiopods were a leading element, while the trilobites, crinoids, corals, and orthoceratites, each in turn, gave distinctive character to the successive faunas. In the Mesozoic era the ammonites took the first place, followed by the pelecypods and the gastropods. The ammonites (Fig. 344) were peculiarly fitted for distinguishing successive horizons, not only because they were free forms, measur-

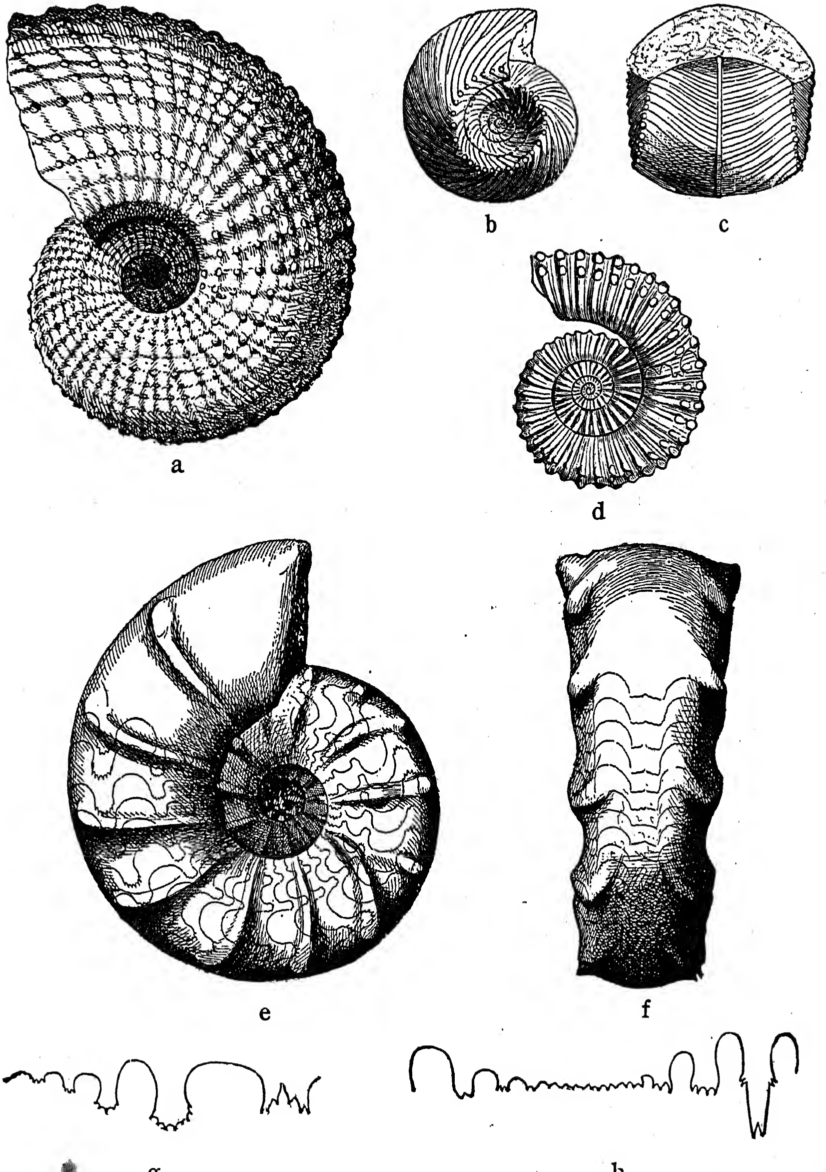


Fig. 344.—A Group of Triassic Cephalopods: *a*, *Trachyceras austriacum* Mojs.; *b–c*, *Tropites subbullatus* Hauer; *d*, *Choristoceras marshi* Hauer; *e–h*, *Ceratites nodosus* de Haan, lateral and ventral views of the shell and two sections of the suture, one (*g*) showing the ventral or siphonal lobe with the lateral lobes and saddles, the other (*h*) showing the dorsal or anti-siphonal lobes, with lateral lobes and saddles.

ably independent of bottom conditions, but because they were steadily and rapidly advancing in organization, and because their shells were so constituted as to delicately record their progress by reason of the marvellously complex sinuosities of the sutures, and by the peculiar registration of their life history. "The *Ammonoidea* preserve in each individual a complete record of their larval and adolescent history, the protoconch and early chambers being enveloped and protected by later stages of the shell; and by breaking off the outer chambers, the naturalist can in effect cause the shell to repeat its life-history in inverse order, for each stage of growth represents some extinct ancestral genus. These genera appeared in the exact order of their minute imitations in the larval history of their descendants, and by a comparative study of larval stages with adult forms, the naturalist finds the key to relationships, and is enabled to arrange genera in genetic series."[1] On this account, not less than for their inherent attractiveness, they merit foremost attention in the characterization of the faunas.

The earlier Triassic faunas.—A great group of ammonites, embracing more than 200 species, formed the leading feature of the early Indian Triassic assemblage of marine life. These ranged from the ceratite family, whose sutures were alternately lobed and serrate (see Fig. 345, *a*), to the true ammonites in which the sutures were as tortuous as the outline of an arbor-vitæ leaf. The *Otoceras*, with ear-like suture lobes (whence the name), characterized the earliest stage, while *Gyronites*, *Proptychites*, *Ceratites*, and *Flemingites* in succession characterized the later stages.

Among these later genera was the ceratite-like genus *Meekoceras* (Fig. 345, *c*), which has special interest because it occurs also in western and southeastern Idaho (Aspen Mountains) with the brachiopod genus *Terebratula* (Fig. 345, *h*) and other forms that link together the American and Asian faunas. The alliance of these forms is sufficiently close to indicate that before the close of the earlier Triassic epoch migratory connections had been established between India and western America. It is significant in this connection that a fauna closely related to this ceratite fauna of India occupied the Pacific border in the vicinity of Vladivostok. In this are found a few species iden-

[1] James Perrin Smith, "Comparative Study of Palæontogeny and Phylogeny," Jour. of Geol., Vol. V, 1897, p. 517.

tical with those of India and others closely related to them. These probably belong to a little later stage than their Indian relatives and suggest that the sea-border tract of the North Pacific was the route of migration from India to western America.

Somewhat later in the early Trias there appeared in the Siberian region (Olenek River) a fauna having some of the same genera as the Indian, but not the particular species common to the Indian and the

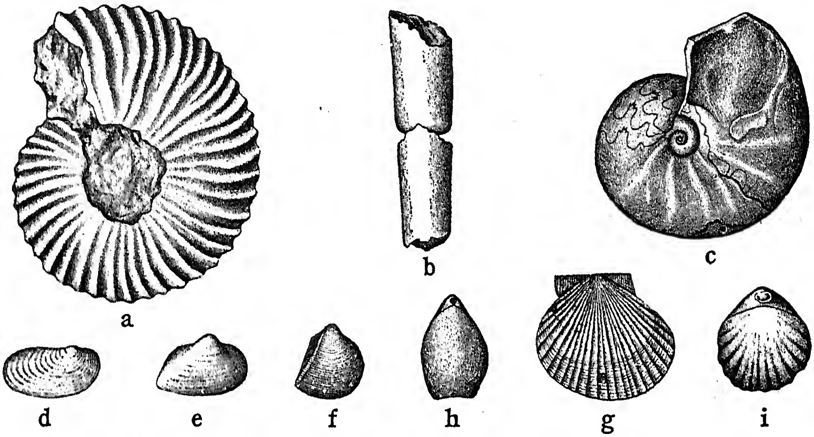


FIG. 345.—A GROUP OF AMERICAN MARINE TRIASSIC FOSSILS. CEPHALOPODA: *a*, *Ceratites whitneyi* Gabb; *b*, *Orthoceras blakei* Gabb; *c*, *Meckoceras*. PELECYPODA: *d*, *Myacites humboldtensis* Gabb; *e*, *Corbula blakei* Gabb; *f*, *Myophoria alta* Gabb; *h*, *Terebratula deformis* Gabb. BRACHIOPODA: *g*, *Pecten humboldtensis* Gabb; *i*, *Rhynchonella æquiplicata* Gabb.

Vladivostok fauna, and hence it is inferred that the Siberian-Indian connection was later than the Indian-Vladivostok. There seems also to have been some form of connection between the Siberian province and the Idaho embayment, for forms closely related to those of Siberia are found in Idaho. After the Indian-Siberian connection had been made, it would be possible for Indian species to reach America either by way of Siberia and the Arctic coast, or by the Pacific sea-shelf, and slight changes involving submergence or emergence in the region of Behring Strait would change the combination of the faunas. It was of course theoretically possible for some species to have been carried by currents across the Pacific without following the shallow-water zones, but this is improbable for all.

The Indian and Siberian provinces seem to have been distinct from the Mediterranean province throughout the earlier Triassic. The Mediterranean fauna was distinguished by many species of *Tirolitinæ*,

a group of ammonites not found in the other provinces, while the ceratite genera named above were wanting or very rare in it.

In California (Santa Ana Mountains) a few fossils have been found which are characteristic of the earlier Triassic of the Alpine province. If further discoveries should prove that the Mediterranean province sent emigrants to the California coast, or received immigrants from it, while Idaho, though in communication with Siberia and India did not receive Mediterranean emigrants, an interesting question as to the respective routes would be raised. The question is indeed raised on other data in a later epoch.

The faunas of the central basin of Europe in the early Trias had very uncertain shifting characters, a part being apparently developed in fresh water, a part in isolated seas, and a part perhaps in dependencies of the ocean. The salt-water life was scant, and its origin and relations uncertain. It seems to have been largely independent of the Mediterranean basin.

The middle Triassic faunas.—By the middle of the Triassic period the provincial faunas had begun to intermingle extensively, and to become composite faunas. The Mediterranean fauna gained access to the Indian basin and to our western coast, and counter-migrations were of course made possible. In western Nevada (Star Peak), species are found that belong to the Muschelkalk horizon of the Alps. With these are forms that are found also in the Siberian province, but the Siberian and Mediterranean faunas, curiously enough, do not seem to have directly mingled. The Mediterranean fauna is found on the shore of the sea of Marmora, which suggests its line of connection with the Indian basin, and representatives are thought to have been found in the vicinity of Vladivostok, suggesting that its route to our western coast lay along the north Pacific sea-shelf. The Siberian connection may have been along the Arctic sea-shelf, in the main, but having communication with the Pacific border at some point north of Nevada; or the Nevada and Idaho basins may have been in communication with one another at this time. The fauna was very rich in ceratites. *Stephanites superbus, Ceratites binodosus*, and *C. trinodosus* of the Himalayas are characteristic types which give name to their respective horizons.

In the Nevada embayment the fauna embraced certain cephalopods that are unknown in the Siberian Trias, but have been found in

the Mediterranean Trias. It, however, still embraced types that appear to have been related to the Siberian forms, from which it is inferred that a connection had been established between the western coast and the Mediterranean province, while a connection with the Siberian region was still retained, but that the Siberian and Mediterranean regions were still not directly connected.

The later Triassic faunas.—During the later stages of the Triassic period, a rather rich marine fauna flourished in California. A large number of its species were identical with or closely allied to species that abounded in the Mediterranean (Alpine) region. Many were also common to the Himalayan region, from which it is inferred that these provinces were in free communication with the west American coast. On the other hand, the Upper Trias of British Columbia contains a quite different fauna, containing a type that belongs to the Siberian group. The British Columbian fauna is perhaps to be regarded as the descendant of the Idaho fauna of the earlier Trias, with additions from Siberian sources, while the California fauna is perhaps a derivative from the Mediterranean and Himalayan provinces by some different route. It has been suggested by James Perrin Smith that this was an Atlantic route, but the traces of the fauna along the route are wanting, owing to the burial of the Triassic marine deposits along the north Atlantic coast. A migratory route by way of Australia, New Zealand, Antarctica, and South America is among the theoretical possibilities.

As already indicated, present knowledge is not sufficient to show the precise nature of the migrations between Europe, Asia, and America during Triassic times, and the suggestions that have been made must be held subject to revision. As developed in America, the special faunas are not ample enough to fairly represent the life of the time, and a general sketch disregarding geographic limits is here substituted.

General nature of the fauna.—The earliest fauna was markedly restricted. In some degree this may be more apparent than real on account of the imperfection of the accessible record, but in the main it was undoubtedly real and due to the physical limitations already sketched. At the same time, there was an increase in the relative degree of differentiation. The conditions which repressed the life, while they reduced the number of individuals, species, and genera, forced them to diverge more and more from one another to accommo-

date themselves to the scant opportunities offered. This is shown best in the development of the land and fresh-water life, but it is also expressed in the marine life.

The cephalopods again in leadership.—The most conspicuous feature was the re-ascendancy of the cephalopods in the form of the ammonites, which had a marvellous development during the period, reaching a thousand species. Their evolution was made the more notable because their structural changes were conspicuous and showed declaredly the advance of each stage upon the preceding. While the straight orthoceratites, the simplest type of the cephalopods, still persisted with notable tenacity, and the simplest coiled nautiloid forms with plane septa also persisted, the closely coiled, intricately sutured forms overwhelmingly predominated. There also appeared at this time the first of the known cephalopods of the cuttlefish type (*Dibranchiata*). The deployment of the cephalopods was therefore varied and comprehensive to a degree never reached before, and perhaps not much surpassed afterward, although the culmination of this evolution took place in the succeeding period. The old forms, however, the orthoceratites and even the goniatites, make their last appearance in this age, and were not participants in the culminating fauna of the Jurassic. The remarkable commingling of old and new forms, orthoceratites, nautiloids, goniatites, ceratites, and ammonites, with its suggestiveness relative to derivations and transitions, makes this one of the most instructive assemblages in the history of the cephalopods.

Old and new gastropod types.—A similar commingling and transitional aspect was presented by the gastropods. The Paleozoic gastropods possessed apertures which were "entire"; that is, nowhere drawn out into a tube for the reception of the siphon. Sometimes there was a recess or slit in the aperture, but no tube or canal. The progressive branch of the Triassic gastropods, however, developed such tubes and originated the canaliculate class. By means of the canaliculate shell, the used waters from the body chamber were carried a longer distance from the orifice by which fresh waters entered the chamber, and thus served a hygienic function.

√**The transition and rise of the pelecypods.**—The Triassic bivalves do not show the transition from the old to the more recent by as conspicuous features as the cephalopods and gastropods, but it was scarcely

less real. The number of pelecypods was relatively large, and the majority of the genera were of the modern type, some being even identical with living genera, but with these were mingled about half as many that still bore a Paleozoic aspect.

The change in the type of brachiopods.—The dominant brachiopod types of the late Paleozoic were outwardly distinguished by broad forms and extended hinge lines, as the spirifers and orthids; the narrower beaked or rostrate forms represented by the rhynchonellas, formed a very respectable minority. In the Triassic period the rostrate forms *Rhynchonella*, *Terebratula*, and allied genera became the predominant class, and have remained so ever since. The spire-bearing forms (*Spiriferina*, etc.) were still present, though rare, and the loop-bearing terebratuloids became much more conspicuous in the Mesozoic faunas.

The echinoids become the leading echinoderms.—Although the echinoderms were not at all strongly represented in the Triassic fauna, the period marks the transfer of echinoderm leadership from the crinoids to the sea-urchins. It also marks a structural change in these. Beginning with the Triassic, the echinoids had twenty rows of plates in belts of two rows each, as the invariable rule, whereas the Paleozoic forms had more. At first they retained the previous regular pentamerous symmetry, but later this gradually gave place to a bilateral symmetry. Many of the Triassic forms were armed with club-shaped spines. The crinoids were generally few, though sometimes locally abundant. Starfishes and brittle-stars were present, but not abundant.

The corals.—While corals were generally rare, in certain favored localities, as at St. Cassian, they were rather prolific. While some of them resembled the Paleozoic forms in being simple and cup-shaped, the compound species took on the modern (*hexacoralla*) form, and the compound Paleozoic (*tetracoralla*) type disappeared. These later compound corals do not seem to have been derived from the Paleozoic compound forms, but from some simple type.

Other forms.—The marine arthropods seem to have been unimportant. Sponges were present in Europe, but have not been found in America; bryozoans were very few; and foraminifera were abundant in favorable situations in Europe. All of these groups presented more or less transitional or modern phases.

While the general aspect of the Triassic marine faunas was emphati-

cally revolutionary, it is important to note, in view of beliefs once current, that it was transitional, and not an abrupt substitution of a new fauna for an old one. Paleozoic types lived side by side with the later forms, though usually represented by new genera. This overlapping and commingling of old and new clearly indicates the gradation of the earlier into the later. The transition was very extraordinary, however, in the apparent rapidity of its progress, and in the extent to which it affected all classes. The fact that most of the new forms were already present in the earliest Triassic indicates that the transition was chiefly made earlier, in the Permian, as already noted. The fundamental cause was with little doubt the readjustment of the earth's surface to internal stresses, and the physiographic and climatic changes consequent upon this readjustment.

CHAPTER XIII.

THE JURASSIC PERIOD.

The eastern part of the continent.—Formations of Jurassic age have not been certainly identified in the eastern half of the continent. Considerable beds which out-crop along the western margin of the Atlantic Coastal Plain have recently been described as Jurassic;[1] but this correlation, at least for the upper part of the series involved, cannot be looked upon as probable, much less as established. The lowest of the beds in question (the Patuxent and Arundel formations of Maryland), lying at the base of the Coastal Plain series, are tentatively referred to the Jurassic[2] with more reason; but even here nothing has yet been discovered which proves this to be their age. The beds in question are thin (350 feet maximum) and closely associated with the Lower Cretaceous of the locality where they occur. The basis for their tentative reference to the Jurassic, rather than the Lower Cretaceous, is (1) their unconformity below other Lower Cretaceous beds, and (2) the presence of certain reptilian fossils which are thought (Marsh) to be characteristic of the Jurassic rather than of the Cretaceous. Concerning the first point it is to be noted that there is an unconformity in the Lower Cretaceous above the doubtful Jurassic, so that this argument cannot be said to have great weight. These possible Jurassic beds do not appear to be of marine origin.

If any of the Coastal Plain beds are to be looked upon as Jurassic, their position and relations emphasize the greatness of the break between this system and the preceding. The Newark series had been uplifted, tilted, faulted and subjected to extensive erosion before the deposition of the doubtful Jurassic beds, which, in their constitution,

[1] Marsh, Am. Jour. Sci., Vol. II, p. 433, 1896. See also Gilbert, Ward, Hill, and Hollick, Vols. IV and V, 1897.

[2] Clark, Journal of Geology, Vol. V, p. 479. Also Maryland Geol. Surv., Vol. I, p. 190.

their distribution, and their stratigraphic relations are much more closely allied to the Lower Cretaceous than to the Triassic. They constitute the beginning of the great series of undeformed beds underlying the Coastal Plain.

If deposits were not making within the present area of the land along the Atlantic coast during the Jurassic period, geological processes of another sort must have been there in operation. As already noted, the Triassic period seems to have been closed by the deformation of the Triassic beds, accompanied by faulting and the injection of lava into the faulted series. Since the uplifted and deformed Triassic system, along with the Appalachian Mountain region, was essentially base-leveled before the Cretaceous period was far advanced, the intervening Jurassic period must have been a time of great erosion, so far as the Appalachian belt and the Piedmont plateau to the east were concerned. The sediments worn from these older beds were of course deposited somewhere, and the site of deposition seems to have been chiefly east of the present coast.

Aside from the doubtful beds referred to above, no Jurassic strata are known on the eastern side of the continent. Marine Jurassic beds have been recently reported from Texas,[1] but they lie to the west of the ranges corresponding to the Rockies. These Jurassic beds are limestone, and though the exposures are limited, their connections are probably southward with the Jurassic of Mexico. In eastern Mexico,[2] Jurassic beds of marine origin are somewhat widespread, the later formations of the period being more extensive than the earlier. The Jurassic system is also said to be represented in the western part of Cuba.[3]

The broad interior of the continent, including most or all of the area which emerged during the closing stages of the Paleozoic, appears to have remained above the sea during the Jurassic period, as during the Triassic. The area of sedimentation was even more limited than during the Triassic period, especially at the east, though later in the period marine sedimentation was more widespread in the west than

[1] Cragin, Discovery of Marine Jurassic Rocks in Southwestern Texas. Jour. of Geol., Vol. V. See also Hill, Am. Jour. Sci., Vol. II, 1897, p. 449, and Physical Geography of Texas, Topographic Atlas, U. S. G. S.

[2] Bol. del. Inst. Geol. de Mexico, Nos. 4, 5 y 6, 1897, and Bain, Jour. of Geol., Vol. V, p. 384.

[3] Hill, Cuba and Porto Rico.

at any time since the close of the Pennsylvanian period. Like the eastern part of the continent, the interior was suffering erosion, but since its altitude was probably low, the erosion effected was less considerable. The post-Paleozoic, pre-Cretaceous erosion in the interior is less well determined than in the Appalachian belt and the Piedmont plateau farther east.

The western part of the continent.—In contrast with the eastern and interior portions of the continent, deposition was in progress in many parts of the west. Along the Pacific coast, the deposition was marine; in the western interior, in the early part of the period, it was in partially inclosed bodies of water which were sometimes salt, sometimes brackish, and sometimes fresh, or in dry basins and valleys. Late in the period, an arm of the sea extended itself over a great area of the western interior (see Fig. 346). For convenience, the terms Lower, Middle, and Upper Jurassic are here used in connection with the system in the west, though they are not in general use in North America.

The Lower and Middle Jurassic of the Pacific coast.—During the epoch represented by the Lower Jurassic beds, corresponding in a general way with the Lias of Europe, marine deposition was taking place on the Pacific coast[1] (California and Oregon) west of the Basin land. Much of the Jurassic of the coastal belt is concealed beneath igneous rock of later origin, so that its original extent is not known. In the latitude of Nevada and Utah, it extended east to longitude 117°. Where both are present, the Lower Jurassic beds generally rest on the Trias conformably, though the younger beds overlap the older system at some points, and fall short of it at others, and locally (some points in the Sierras) there is unconformity between them. The deposits of the Lower Jurassic embrace all the usual sorts of sedimentary rocks. Beds of corresponding age are not known in British Columbia, and this part of the coastal belt was probably land, and suffering erosion.[2] Early Jurassic beds occur in some of the islands

[1] For the Jurassic of the Pacific coast, see Hyatt, Bull. Geol. Soc. of Am., Vol. III, and Vol. V, both articles chiefly paleontological; Meek, Paleontology of California, Vol. I, and the following folios of the U. S. Geol. Surv.: Bidwell Bar, Colfax, Downieville, Jackson, Lassen Peak, Maryville, Mother Lode, Nevada City, Pyramid Peak, San Luis, Sonora, Truckee, Cal., and Roseburg, Ore.

[2] Dawson, Science, March 15, 1901.

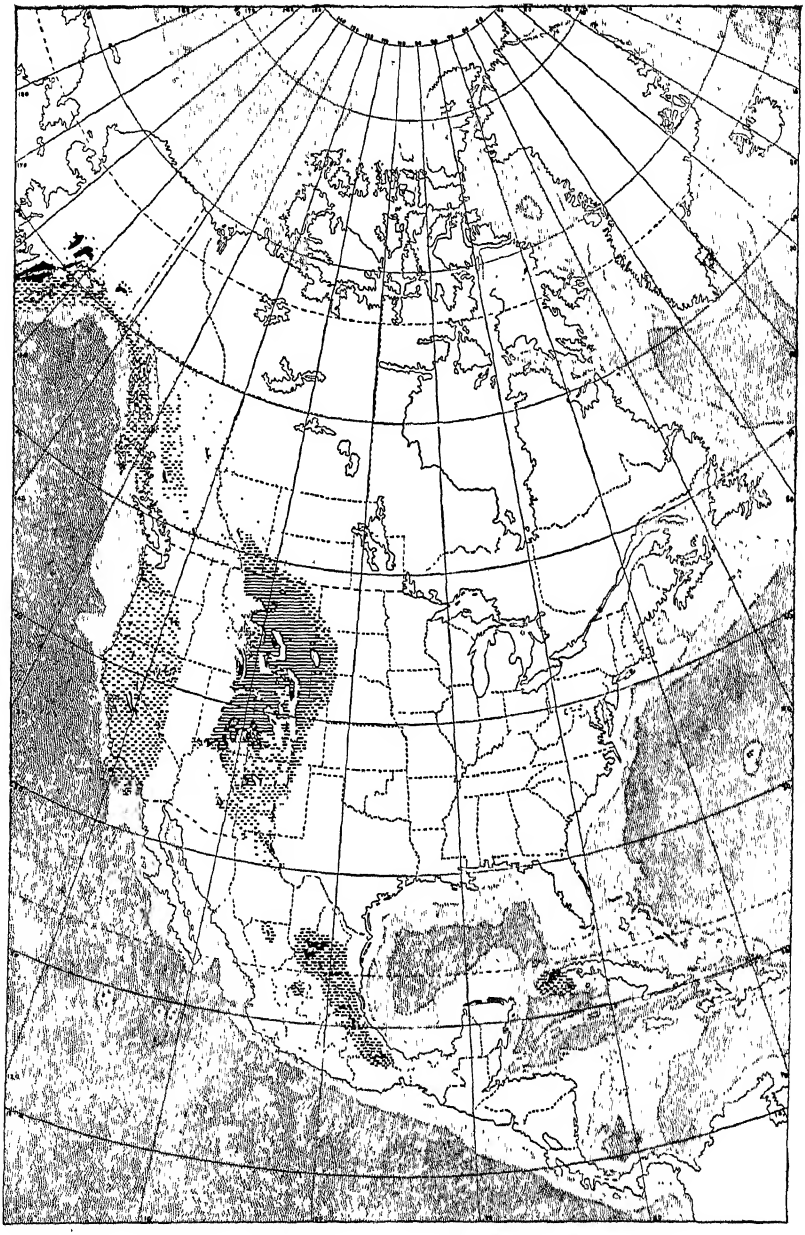


FIG. 346.—Map showing the areas where the Jurassic system appears at the surface in North America. The conventions are the same as in preceding maps.

farther north. The fossils of the early Jurassic beds point to faunal connections with central Europe.[1]

The Middle Jurassic of the Pacific coast, corresponding in a general way with the Lower Oölitic of England, and the Middle Jura of the continent of Europe, has a distribution similar to that of the Lower, and its close association with the latter allies it closely with the Trias stratigraphically. The auriferous slates of California, a meta-sedimentary series, involve some Jurassic beds as well as those of greater age (Trias, Carboniferous, and Silurian).[2]

Lower and Middle Jura in the western interior.—Between the meridians of 106° and 112°, and the parallels of 35° and 42°, there are beds of a sandy nature which have often been referred to the Jurassic system. Their distribution is more restricted than that of the Permian and Triassic Red Beds already referred to. The lower beds which have been regarded as Jurassic are without fossils, and correspond, in their general character, with the Permian and Triassic of the same region.

The beds of the western interior usually referred to the Permian, Triassic and early Jurassic, have the appearance of a unit. Their general (though not universal, see p. 26) conformity among themselves and with the Carboniferous below, seems to show that their deposition followed the Carboniferous without notable interruption in most places; but such evidence is to be received with caution, as seeming conformities sometimes conceal great intervals. Since their thickness is not great—600 feet perhaps is an average—and since so slight a thickness of coarse sediment does not seem to call for a long period of time, there is some doubt whether any part of the Red Beds is so young as Jurassic. The region of the Red Beds may have been a land area, and subject to degradation during the early part of the Jurassic period. In the later part of this period, as will be shown later, the sea found access to the northern part of the Great Plains area. If the Red Beds were suffering erosion during the earlier part of the Jurassic period, and the region to the south throughout the whole period, the thickness of the Permo-Triassic formations may have been greatly reduced before the deposition of the Upper Jurassic and Lower Cretaceous formations. In any case, the existence of

[1] Smith, J. P., Jour. of Geol., Vol. III, 1895, pp. 377–8.

[2] Idem., Bull. Geol. Soc. of Am., Vol. V, p. 257.

Early and Middle Jurassic beds in the western interior must be looked on with question.

The Upper Jurassic.—During the Upper Jurassic (Upper and Middle Oölitic of England) epoch, the areas of sedimentation were greatly changed, indicating considerable changes in geography. On the Pacific coast of the United States, in the latitude of California, the sea appears not to have extended east of the Sierras. The Golden Gate series of the Coast Range perhaps belongs to this stage;[1] but in northern British Columbia, where the Lower and Middle Jurassic beds have little representation, the sea extended farther east than during the earlier part of the period. South of the United States, Jurassic beds of marine origin occur in western Mexico (Sonora), but it is not known to what part of the system they belong.

In addition to marine sedimentation along the Pacific coast, the sea had access to a large area in the western interior, and covered much of Wyoming,[2] Montana,[3] Utah, and Colorado, and parts of several other states.[4] This is shown by the presence in these States of sedimentary beds containing marine Upper Jurassic fossils. The beds are chiefly exposed in the mountains (Wasatch, Uinta, Black Hills, etc.) where the erosion which followed the uplift and deformation of the strata has discovered their edges.[5] The general relations of land and water in the west in the late Jurassic are shown in Fig. 348, but it should be said that the distribution of the Jurassic in the west is so imperfectly known that no map showing the relations of land and water can lay claim to accuracy.

The avenue through which the sea reached this region has not been determined, but the fossils are so unlike those of the Californian coast as to have led to the inference that the waters of the interior did not come in from the southwest. The absence of Jurassic strata over

[1] Fairbanks, Jour. of Geol., Vol. III, pp. 415–433.

[2] Logan, Jour. of Geol., Vol. VIII, p. 241; Knight, Bull. 45, Wyo. Exp. Station, and Bull. Geol. Soc. of Am., Vol. XI, pp. 377–88, and the following folios, U. S. Geol. Surv.: Hartville, Wyo., Yellowstone Park, Wyo., New Castle, Wyo.-S. D.

[3] See Little Belt Mountain, Fort Benton, Three Forks and Livingston folios, U. S. Geol. Surv.

[4] For South Dakota, see Darton, 21st Ann. Rept. U. S. Geol. Surv., Pt. IV, and the following folios, U. S. Geol. Surv.: Oelrichs and Edgemont, S. D.-Neb.

[5] In addition to the above folios, U. S. Geol. Surv., see also the following: Anthracite and Crested Butte, Ten Mile, and Telluride.

the belt marked as land in Fig. 346, lends further support to the conclusion that a land barrier separated the interior waters from those of the Californian coast. The identity of many species from the Upper Jurassic beds of the Queen Charlotte Islands and from the Frazer River in British Columbia, with those of the western interior, imply either connection between these areas, or connection of both with some point along the migratory routes which the marine life followed. Whether this connection was direct through British Columbia, or

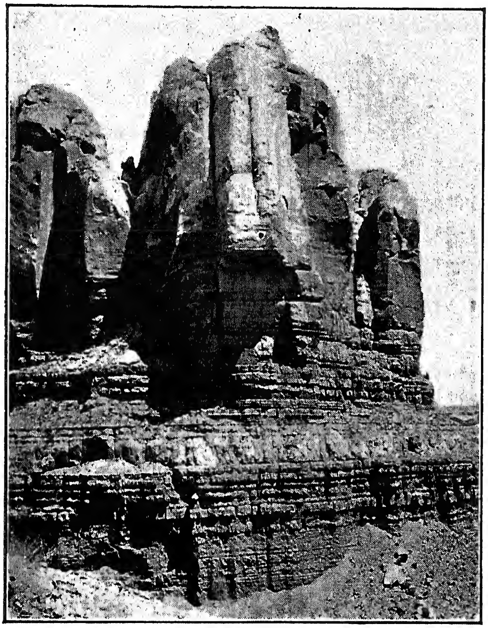


FIG. 347.—A cliff of Jurassic rock, 1½ miles west of Bluff City, Utah. (Cross, U. S. Geol. Surv.)

whether it was by way of Alaska, east of the Rockies, is unknown. The similarity of the Upper Jurassic marine fossils of America and of Russia, more fully set forth later, would be explained by either of these connections; so also would the fact that a few of the species of the Californian coast are identical with those of the Queen Charlotte Islands. Either connection would call for an extension of the Jurassic beds of Montana, Dakota, Wyoming, etc., to the north or northwest. In spite of the fact that such extension has not been demonstrated,

the most rational explanation of the Marine Jurassic beds in question is that they were deposited in a great dependence of the north Pacific or the Arctic Ocean,[1] which covered the area where the strata occur. If this be correct, it must be supposed that the northerly extension of the marine Jurassic of the United States has been concealed by later beds, or destroyed by erosion, or not discovered.

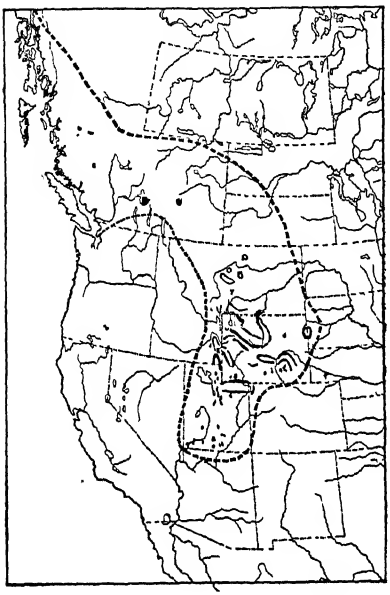


FIG. 348.—Map showing the general relations of land and water in the western part of North America during the later part of the Jurassic period. The black areas represent known areas of Upper Jurassic. The dotted line is the conjectured outline of the bay. (After W. N. Logan.)

The presence of fresh-water beds of possible Upper Jurassic age (the Morrison [Atlantosaurus, Como] beds of Colorado, Montana, and Wyoming) in some parts of the western interior would, were their age established, show that salt water was not continuously present at all points where deposition was taking place. The Jurassic age of these beds seems, however, to be doubtful (see p. 119).[2]

The change in geographic conditions in the western half of North America, between the Middle and Upper Jurassic, as shown by the distribution of the corresponding formations, was as great as that which sometimes separates one period from another. It was equally great in other continents, but not in other parts of our own.

Thickness.—The total thickness of the system in California does not exceed 2000 feet (in part tufa). Farther east, in western Nevada,[3]

[1] Neumayr suggested (Denkschr. K. Akad. Wiss. Wien, 1893, pp. 301–302) the Arctic rather than the Pacific connections of the Jurassic deposits; but the similarity of faunas of the north Pacific coast and the western interior, have commonly been thought to point to the other conclusion.

[2] Lee, Jour. of Geol., Vols. IX and X, pp. 343–52 and 36–58 respectively; Darton and Smith, Edgemont and New Castle, South Dakota, folios, U. S. Geol. Surv., and Williston, Jour. of Geol., Vol XIII, p. 338.

[3] King, Survey of the 40th Parallel, Vol. I.

nearer the land whence sediment was derived, the system attains a thickness of 5000 to 6000 feet, being made up of 1500–2000 feet of limestone below, and 4000 feet of slates above. In its western interior, it is far less.

Surface distribution and position of beds.—In spite of the fact that the Jurassic beds are somewhat widely distributed, they do not now appear at the surface over large areas. In many places they are covered by younger beds, and from some areas where they once existed they have been removed by erosion. In some areas they retain their original position, while in others they have been tilted, or even folded and metamorphosed. This is especially true in California, where the slates of the system contain many of the gold-bearing quartz veins of the region.

With the sedimentary beds of the Pacific coast (California) there are considerable beds of fragmental igneous rock, showing that volcanic forces were here active on a somewhat extensive scale during the Jurassic period.

Jurassic in Alaska.—Jurassic formations are known at somewhat widely separated points in Alaska, but their horizon within the system has not been established.[1]

CLOSE OF THE JURASSIC.

Orogenic movements.—At the close of the Jurassic period considerable disturbances occurred in the western part of North America. Nearly 25,000 feet of strata, 7000 feet of which belong to the Triassic and Jurassic, began to be folded into the Sierras,[2] and the Cascade and Klamath[3] Mountains farther north perhaps began their growth at the same time. In northern California and southern Oregon, in the latitude of the Klamath Mountains, the coast was somewhat farther west than now, after this period of orogenic movement.[3] There is some reason to think that the axes of these mountain ranges were the scenes of earlier disturbances (Vol. II, p. 584), but of these earlier movements the record is meager. Their existence is inferred from the greater complexity and metamorphism of the pre-Triassic beds. It

[1] Spurr, 20th Ann. Rept. U. S. Geol. Surv., Pt. VII, pp. 235–6.

[2] Whitney, Geology of California, Vol. I, and Am Jour. Sci., Vol. XXXVIII, 1864; and Fairbanks, Am. Geol., Vol. IX, 1892, Vol. XI, 1893.

[3] Diller, Bull. Geol. Soc. Am., Vol IV, p. 224, and 14th Ann. Rept. U. S. Geol. Surv.

FIG. 349.—Section in southwestern South Dakota. *Pr*, Proterozoic; *Ꞓ*, Cambrian (Deadwood sandstone); *Mp*, Mississippian (Pahasapa and Englewood limestones); *Pm*, Pennsylvanian (Minnelusa sandstone); *Pm*, Permian (?) (Minnekahta limestone and Opeche shale); *Ts*, Triassic (Spearfish shale); *Ju*, Jurassic (Unkpapa sandstone); *Cm*, Comanchean (Morrison formation); *Kdl*, Comanchean below and Cretaceous above (Lakota and Dakota sandstones). (Edgemont, S. D. Folio, U. S. Geol. Surv. Vertical scale ×2. Darton and Smith.)

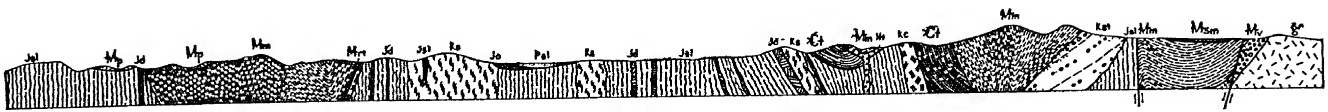


FIG. 350.—Section showing position and relations of the Jurassic system at and near the coast in southern California. *Jsl* = Jura-Trias (San Luis formation); *C*, Comanchean (Toro formation); *Kat*, Cretaceous (Atascadero formation); *Mv* and *Mm*, Miocene (Vaquero and Monterey formations); *Ms* and *Mp*, late Miocene or Pliocene; *Pal*, Pleistocene. The upper left-hand corner of the figure is at sea-level. (Fairbanks, U. S. Geol. Surv.)

is not to be understood that the Sierras and Klamaths attained mountainous heights immediately at the end of the Jurassic period, or that they have not had subsequent periods of growth. In the Klamath Mountains, for example, there are deformed beds of late Tertiary age. It is probable that the Coast Range of California began its history at the same time, for deformed Jurassic beds (Golden Gate series) underlie the Lower Cretaceous unconformably in the axis of the range;[1] but the movements which gave the Coast Range its present form, or its present form as modified by erosion, took place at a much later time.

Farther east, the Humboldt ranges of Nevada are thought to have been started in their development at about the same time as the ranges already mentioned. More than 20,000 feet of Jurassic and Triassic strata are involved in their folds. It is possible that other mountains of the west, the cores of which had been islands throughout the Triassic and Jurassic periods, were affected by renewed uplift at this time of general disturbance. The orogenic disturbances at the close of the Jurassic may have been comparable in kind and in extent to those which affected the continent at the close of the Paleozoic, but they were probably of a lower order of magnitude. The disturbances which have been definitely referred to this period were certainly less extensive, and less intense.

The position and relations of the Jurassic formations at various points in the west are shown in Figs. 351 to 354.

Changes in geography.—At the close of the Jurassic, geographic changes equal in extent to those of the closing stages of the Paleozoic

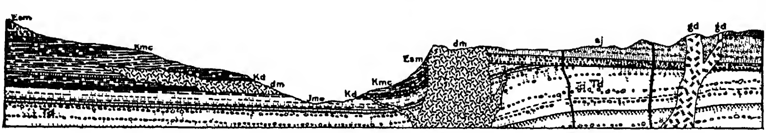


FIG. 351.—Section showing the relations of the Jurassic system near Telluride, Colo. *Td*, Triassic (Dolores formation); *Jme*, Jurassic(?) (McElmo formation); *Kd* and *Kmc*, Cretaceous (Dakota and Mancos formations); *Esm*, Eocene (San Miguel formation); *dm* and *gd*, igneous intrusions (Purington, U. S. Geol. Surv.)

are not recorded; yet the changes were great, though in regions less well known than those affected by the deformative movements which occurred late in the Paleozoic era. Much, if not all, of the great Upper

[1] Fairbanks, Jour. Geol., Vol. III, pp. 415–430, and Smith, Bull. Geol. Soc. of Am., Vol. 5, pp. 257–8.

Jurassic gulf of the northwestern part of the continent disappeared at the close of the period.

It should perhaps be added that until very recently no part of

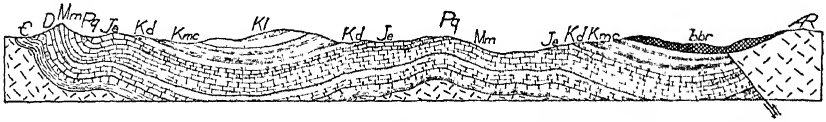


FIG. 352.—A section in southern Montana. *Æ*=Archean, *€*, Cambrian (Flathead and Gallatin formations); *D*, Devonian (Jefferson and Three Forks formations); *Mm*, Mississippian (Madison formation); *Pq*, Pennsylvanian (Quadrant formation); *Je*, Jurassic (Ellis formation); *Kd*, *Kmc*, and *Kl*, Cretaceous (Dakota, Colorado, and Montana, and Laramie formations); *bbr*, igneous rock. (Peale, U. S. Geol. Surv.)

the geology of the United States has received less careful study, and is less well understood, than that of the Permian, Triassic, and Jurassic

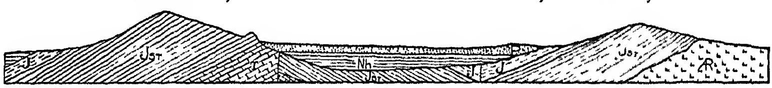


FIG. 353.—Section showing the relation of the Jurassic beds in the West Humboldt range of Nevada. *Æ*, Archean; *T*, Red beds; *Jst*, Triassic (Star Peak); *J*, Jurassic; *Nh*, Pliocene; *P*, Pleistocene. (King, U. S. Geol. Surv.)

systems of the western half of the continent. The reason is twofold: (1) The systems are in regions where relatively little detailed work

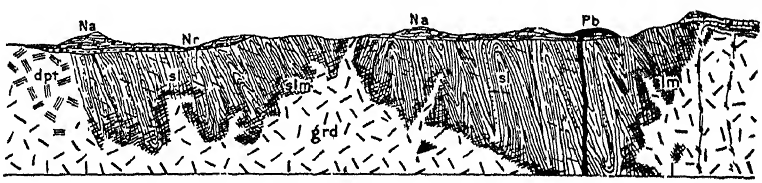


FIG. 354.—Section in the Sierras of California, showing the Jurassic (or Jura-Trias) system where it has been metamorphosed and where it is associated with igneous rock. *grd* and *dpt*, igneous rock, probably of Jurassic or Cretaceous age; *sl* and *slm*, Jura-Trias (?) schist; *Na*, *Nr*, and *Pb*, igneous rock of late Tertiary and Pleistocene age. (Lindgren, U. S. Geol. Surv.)

has been done, and (2) the non-marine character of most of the beds and their paucity of fossils, makes their interpretation difficult.

FOREIGN JURASSIC.

Europe.—Jurassic strata are exposed in many and widely separated localities in Europe, though for the most part in relatively small areas only. They appear at the surface in a wide belt across England, from

the Bristol channel on the southwest to the mouth of the Humber on the northeast. They encircle, with outward dip, the ancient metamorphic rocks in southern France, and with inward dip they form the border of the Paris basin, the central part of which is filled with younger beds. East of the Paris basin, the upturned beds of the system appear in the Jura Mountains (whence the name) and the Alps, and farther east in various parts of the complex mountain system of south central Europe. In the lower latitudes of the continent they are to be found in Portugal, in some parts of Italy, in the Balkan peninsula, in the Crimea, and in the Caucasus Mountains, and in the north over large areas in central and northern Russia. The only considerable tract where they do not occur is the northwestern part of the continent.

This enumeration shows that the Jurassic system is widely distributed in Europe, but as with older systems its present distribution at the surface is no measure of its real extent. It has been thought that the Jurassic of England is probably continuous with that of France beneath the English Channel, and thence, by way of southeastern France, with those parts of the system which appear about the Mediterranean, and by way of Belgium, the Netherlands, and the German lowlands, with those parts of the system which appear in Poland and Russia. In northern Russia, the surface distribution of the system corresponds approximately with its real distribution. In southern Russia, on the other hand, the Jurassic beds are probably widespread beneath younger formations. Jurassic strata of marine origin have a much wider distribution in Europe than in North America, and hence it is inferred that a larger proportion of the former continent was submerged during at least some part of the period.

It is not to be inferred that all parts of the Jurassic system are so widely distributed. The lower part is less widespread than the Middle, and the Middle is less widespread than the Upper. In this respect, the North American and European continents are in harmony.

The areas of Jurassic deposition in Europe are commonly grouped into three provinces, the southern, the central, and the eastern; but they are equally well grouped in two provinces, a Mediterranean province and a Boreal province.

It is not to be understood that these provinces, whether three or two, were absolutely separated from one another, or that they were

equally distinct at all stages of the period;[1] but their separation was sufficient to give rise both to different conditions of sedimentation, and to different conditions of life. The changes which took place during the period are best understood by a study of the character and distribution of the various parts of the system.

It may be noted at the outset that the Jurassic system of Europe has been studied in great detail, and that the correlation of its different horizons has been carried to a degree of refinement not known in any older system in Europe, and not in any system in America. About thirty well defined horizons have been made out for central and western Europe, and these have been found to hold over wide areas outside the region where they were first recognized. The definition of these horizons is based on fossils, and chiefly on the fossils of free-swimming animals. The fixed forms of life, and those which are confined to shallow water, ranged less widely, and their fossils do not enter into the definition of the many horizons in any important way. Some of the horizons which are but a few feet in thickness are traceable over large areas of the continent, though not beyond the limit of a geological province. Thus in Great Britain, 17 distinct ammonite zones have been recognized in the Lower Jura (Lias) alone, and this zonal succession has been found to apply to all central and western Europe.[2]

By the definition of these provinces and by the detailed study of the distribution of the various types of life within them, much has become known concerning the geography of the Jurassic period beyond that which is shown by the mere distribution of the Jurassic beds.

Although the subdivision of the Jurassic system has been carried to a high degree of refinement, the many zones are grouped into a few principal divisions as follows:

Germany, 2000′–3000′.	England, 4000′–5000′.
Upper Jura (White Jura, Malm)	Upper Oölite (Portland Oölite)
Middle Jura (Brown Jura, Dogger)	Middle Oölite (Oxford Oölite)
Lower Jura (Black Jura, Lias)	Lower Oölite (Bath Oölite) Lias

Lower Jura or Lias.—Conditions similar to those of the last stage of the Triassic period affected central and western Europe during

[1] De Lapparent, op. cit., p. 1105.
[2] Geikie, op. cit., p 1136.

the early part of the Jurassic, and the Lias frequently overlies the Trias conformably, and with no very definite plane of demarkation. The early Jurassic beds are mostly marine, and were deposited in waters which were shallow, and the sediments were mostly clastic and fine. Near its eastern border in central Europe, the Lias contains coal in quantity, as many as 25 workable coal beds occurring at one point in Hungary. In other places, too, as in England, there are indications of non-marine conditions of sedimentation, both in the fossils and in the thick beds of earthy iron carbonate of commercial value.[1] Some of the Liassic shales of Germany afford oil.[2]

The Lias of southern Europe is more largely calcareous than that of central Europe. Red marble, carrying abundant ammonites, is a characteristic formation of the eastern Alps, the Carpathians, the Apennines, and in Spain.

In the eastern province of Europe, the Lower Jura is unknown. It occurs in the southern part of Russia (the Caucasus Mountain vicinity), but this is classed with the southern rather than with the eastern province.

Middle Jura.—The Middle Jura, and especially its upper part, is somewhat more widespread than the Lower, in central Europe, indicating progressive sea-encroachment. During the early part of the epoch, the deposits, like those of the Lias, were uniform over considerable areas, but during the later part, they became more diverse so far as their fossils were concerned, showing that conditions sufficiently different to influence life, affected various parts of the province.

Oölite is one of the characteristic formations of the Middle Jura of central Europe as of England. The prevalence of this rock originally gave origin to the name *Oōlitic* for all that part of the system above the Lias. The oölitic structure affects not only much of the limestone, but also lenses and beds of iron ore, in various parts of the central province. In England, parts of the Middle Jurassic contain estuarine and fresh-water beds, and sometimes (as in Yorkshire) coal seams and beds of iron ore. Marine Upper Jurassic beds overlie the non-marine parts of the Middle Jurassic.

In southern Europe, the Middle Jura has but little representation, or has not been thoroughly differentiated. In the eastern province,

[1] Geikie, op. cit., p. 1132.
[2] Idem , p. 1154.

the larger part of the Middle Jura is wanting, though the upper horizons may be present. Middle Jurassic beds in Lat. 71° have yielded species of sub-tropical ferns, cycads, and conifers.[1]

The Upper Jura.—The encroachment of the sea which was in progress during the Middle Jurassic time reached its maximum a little later

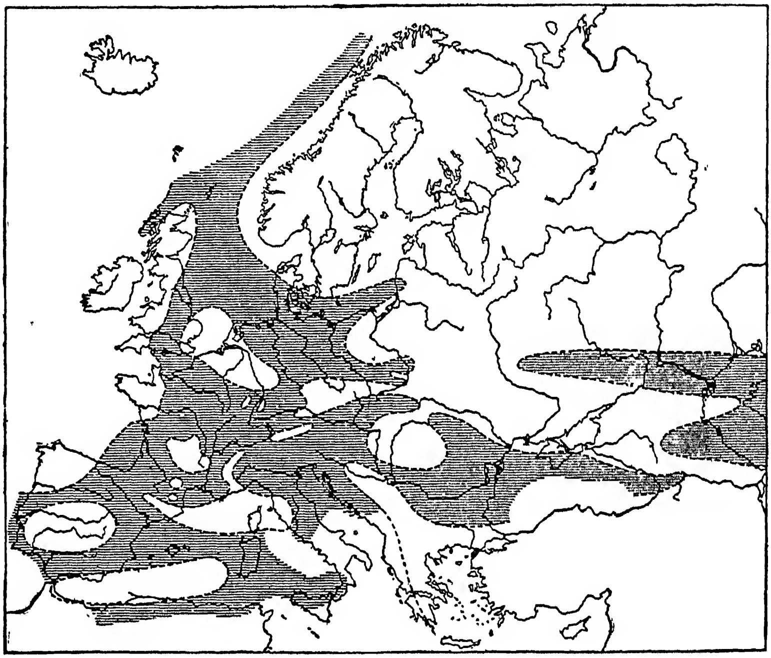


FIG. 355.—Sketch-map of Europe in the Middle Jurassic period. The shaded areas are areas of deposition, chiefly marine. (After De Lapparent.)

as shown by the wide distribution of the Upper Jurassic formations; but before the end of the epoch the sea began to withdraw, for some parts of the area which had been submerged became land, while other parts were occupied by lakes and bodies of brackish water.

The formations of the Upper Jurassic in central Europe contain much more limestone than those of the lower divisions of the system in the same province. Corals and sponges were especially abundant in central Europe, and contributed much to the making of the light-colored limestone which, on the continent, has given this member

[1] De Lapparent, Traité de Geologie, p. 1142.

of the system the name of the White Jura. Some of the sandstones also are white.

One of the notable phases of the Upper Jurassic in central Europe is the Solenhofen limestone of southern Germany. This stone is so fine and so even grained, and at the same time so workable and so strong, that it has come into use the world over for lithographic purposes. It is also remarkable for the perfection of its fossils, including

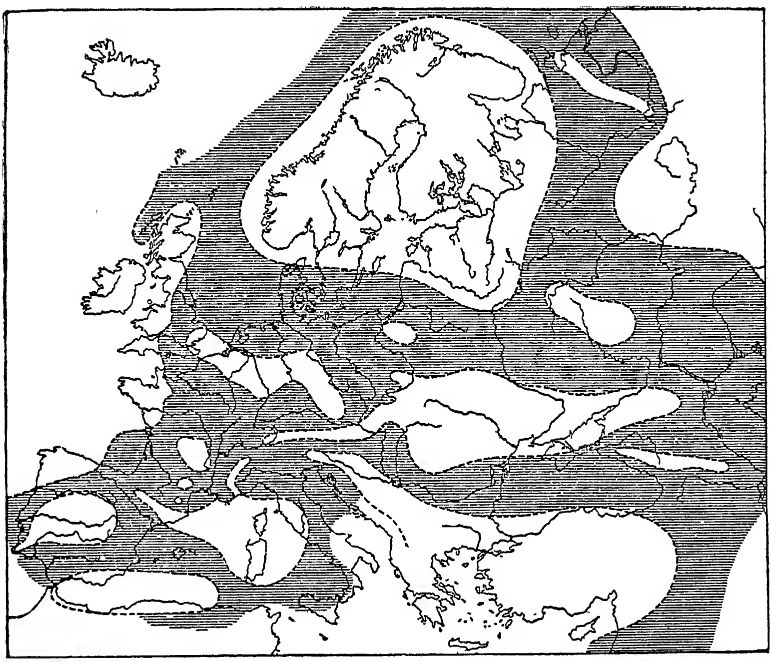


FIG. 356.—Sketch-map of Europe showing the relations of land and sea during the later part of the Jurassic period. The shaded areas were submerged. (After De Lapparent.)

such delicate parts as the gauzy wings of insects. This limestone has been ascribed to a late stage of the epoch, after the land to the north had emerged. The newly emerged beds, largely limestone, were still soft, so the hypothesis runs,[1] and the material washed down from them gave origin, after deposition, to the lithographic stone. Others have thought to see in the even grain of the stone a chemical precipitate. Whatever the origin of the limestone, the perfection with which

[1] Neumayr, loc. cit., p. 318.

delicate parts of various sorts of animals are preserved, shows that the conditions of sedimentation were unusual.

The uppermost horizons of the Jura are wanting in most of the central provinces of Europe, but in England and northern Germany, and at a few points elsewhere, brackish water deposits of the last stages of the epoch are known. In England, these beds (Purbeck) are closely associated with the oldest beds (Wealden) of the next period.

The Upper Jurassic of southern France and of the Mediterranean province, largely limestone,[1] differs from that of central Europe in recording more uniform conditions. In Portugal, however, the higher members of the Upper Jura are not altogether marine, and the system grades up into the non-marine Lower Cretaceous.[2] Even where the upper part of the Jurassic of southern Europe is marine, it is closely connected with the Lower Cretaceous. In this respect, southern Europe is in contrast with the central part of the continent, where the separation of the Jurassic from the Cretaceous is complete.

In the eastern province of Europe, the Upper Jura (with late Middle Jura) is widespread. The sea which covered this province is thought to have come in from the north, and to have covered much of Russia. The strata of this province are rather uniform in composition, and mainly clastic, the sands being often glauconitic. In the eastern as in the southern province, the Jura goes over into the Cretaceous without stratigraphic break.

The Jurassic system attains a very considerable thickness both in the central and southern provinces.

The frequent alternations of muddy, sandy, and calcareous sediments, which are a marked feature of the system in England and northern France, indicate frequent pauses and reversals of the changes affecting either the depth of the water, or the height of the adjacent land, or both. In the failure of petrographic characters to persist through considerable thicknesses, the Jurassic system of the central province is in contrast with most of the systems of the Paleozoic.

In igneous rocks, the Jurassic system of the south and central provinces of Europe is poor. Such rocks enter into the system in western Scotland (Sky, Mull), and the date of their origin is about the close of the Middle Jura.

[1] Geikie, op. cit., p. 1148.
[2] Idem, p. 1157.

Throughout much of western Europe, the Jurassic beds are still nearly horizontal, but in the Jura Mountains, in the Alps, and other mountains of the south central system of Europe, as well as in the Caucasus, they are tilted and sometimes closely folded. Where they have been undisturbed they are often unindurated. In the eastern province the deformation of the beds is not great.

Extra-European Jurassic.

Arctic lands.—The Upper Jurassic formation is found in Spitzbergen, Nova Zembla, Franz Josef Land (Russian type of fauna), over a large part of Siberia, and in the New Siberian Islands to the north, in the Aleutian Islands which form the connecting link between Asia and America, in Alaska, in some of the Arctic Islands of North America, and in eastern Greenland. This distribution means a great Arctic Sea in the Late Jurassic epoch, with two considerable dependencies to the south—the one in Russia, the other, as we have already seen in western North America. In all of the high latitudes where the Upper Jurassic strata are widely distributed, the Lower Jura is wanting, as far as known, and in most of them the Brown Jura also.

Asia.—The Lias is not known in central Asia, but it occurs in Asia Minor, north Persia, Assyria, the Himalayas, and Japan.[1] The Middle Jura, largely clastic and of terrestrial origin, is wide-spread in northern Asia, some beds containing much carbonaceous matter. Marine Middle Jura is known in northern India.[2] The Upper Jura is known at various points in Asia Minor, in the Himalayas, in Tien Shan, Japan, and Siberia. It covers great areas in the basins of the Olensk, the Lena, the Jana, the Yenesei, and the Obi Rivers,[3] and in Kamtschatka, but is not known in central Asia. The Jurassic strata, especially the Upper Jurassic, are therefore widely distributed in Asia as in Europe.

Africa.—So far as now known, the marine Jurassic of this continent is confined to the northern and eastern coasts. Marine Lias is known only in Algeria and western Madagascar; the middle and upper parts of the system occur both in the north and in the southeast. The western coast of India and the eastern coast of Africa, including

[1] De Lapparent, op. cit., pp. 1084 and 1101.
[2] Idem, p. 1142.
[3] Idem, p. 1233.

Madagascar, seem to have been parts of the same marine province at this time.[1]

Australia.—The Lias is known both in New Zealand and Borneo, but Australia was probably land during this epoch. The Middle Jura is known in New Zealand, New Guinea, and in western Australia, where clastic beds rest unconformably on much older rocks.[2] In Queensland, non-marine Jurassic formations are known. The rocks are largely clastic and include valuable beds of coal.[3]

Central and South America.—The Lias is well developed in Mexico, Peru, and the Bolivian Andes, Chili, and Argentina, and in the last-named country it contains coarse conglomerates and volcanic tuffs.[4] The Middle Jura occurs in Bolivia and Argentina, while the Upper Jura is wide-spread in Mexico, and occurs in Chili and Argentina.

Coal.

Coal of considerable value is somewhat widely distributed in the Jurassic formation. Besides that in the Lias of Hungary, it occurs in the Caucasian region, Persia, Turkestan, southern Siberia, China, Japan, and Farther India, in many of the islands southeast of Asia, and in Australia and New Zealand. In the last-named country, the coal-bearing formations are interbedded with marine strata, suggesting considerable oscillations of level. In most of these countries, the coal is Liassic. Outside of North America, it is probable that no other system, except that of the Carboniferous, contains so large an amount of coal as the Jurassic.

Geography of the Jurassic Period.

From the distribution of Jurassic strata, and from the study of their fossils, it has been possible to draw many inferences concerning the distribution of land and water during the period. From such data, Neumayr has attempted to outline[5] in a general way the land and water areas of that stage of the Jurassic period when the sea was most wide-spread. One of the striking things shown by his map is

[1] De Lapparent, op. cit , pp. 1178, 1205, 1236.
[2] Idem, pp. 1084, 1101, 1145.
[3] Geikie, op. cit., p. 1161.
[4] Kayser, Geologische Formationskunde, p. 382.
[5] Erdegeschichte, Vol. II, p. 336.

the great expanse of land in the tropical latitudes, and the great expanse of sea in the Arctic regions. According to Neumayr's conjecture, the late Jurassic expansion of the sea was one of the greatest known in geological history, and the distribution of the land at the time of the maximum extension of the sea was very different from that which existed in the Lias, when there was a great expanse of land in the Arctic latitudes.

Climate.—The testimony of fossils gathered in various parts of the world is to the effect that the climate of the Jurassic period was genial. In Europe, corals lived 3000 miles north of their present limit, and saurians and ammonites flourished within the Arctic circle. Nevertheless, climatic zones were probably defined at that time.[1] Corals are unknown in the deposits of the great Arctic belt of Upper Jura, and the detailed study of the faunas has led to the belief that three more or less well defined zones were in existence. One is recorded in the Jurassic beds of the Arctic belt; a second in the deposits of the central European belt; and a third in the southern province of Europe, and in the lands farther south.

There can be no doubt of the great differences in the faunas of these different provinces, but it is not certain that the differences were due wholly or even mainly to climatic influences.

It should perhaps be noted that there are conglomerates in the Lias of Scotland which have been conjectured to be glacial,[2] but there is no proof that this was their origin.

Close of the Jurassic in Europe.—The close of the Jurassic appears to have been marked by a somewhat widespread emergence. In the central province, this disturbance appears to have begun before the close of the Jurassic, for the latest beds (Purbeck) referred to that period in England are unconformable on beds lower in the series. Similar changes are known to have occurred in late Jurassic time in some other regions; but the Upper Jurassic and the Lower Cretaceous beds are in many regions so closely associated as to show that no change of continental dimensions intervened between them. Great deformative movements seem to have affected no part of Europe at the close of the period.

[1] Neumayr, loc. cit., p 331.
[2] J. Geikie, Outlines of Geology.

The Jurassic Life.

As the Jurassic seems to have been mainly a period of sea extension, correlated with a base-leveling of the land, the marine life again assumes a place of leading importance. At the same time the land life, though suffering somewhat by the limitation of its territory during the stages of sea transgression, was favored by the subdued attitude of the land and the genial climate. The frequent shiftings of land- and sea-areas, without involving great topographic relief or severe climatic states, conduced to changes in the forms of life which were on the whole progressive and expansional, though necessarily retrogressive in particular phases.

The Marine Life.

It will be recalled that a markedly expansional stage of epicontinental sea life had set in toward the close of the Trias. This held on into the Jurassic, fluctuating with the sea expansions and retrogressions, but in general progressing until it reached a climax in the latter part of the period, when the sea attained the limit of its remarkable transgression upon the land. Later there was a measurable decline closing the period. As already indicated, this faunal progress is far less well revealed in North America than in Europe and Asia, and a general sketch drawn chiefly from the Old World may well precede a special statement of the more meager American development.

The great features of the marine life lay in (1) the continued dominance of the ammonites among the invertebrates, (2) the rise of the belemnites, (3) the abundance and modernization of the pelecypods, (4) the rejuvenation of the corals and crinoids, (5) the marked development of the sea-urchins, (6) the introduction of crabs and modern types of crustaceans, (7) the prevalence of foraminifera, radiolarians and sponges, and (8) the change in the aspect of the fishes, while (9) all were dominated by the great sea-serpents evolved from the land-reptiles of the Trias.

(1) The ammonites which, in certain respects, reached their climax in the later stages of the Trias, were still the master type among invertebrates, and were represented by many beautiful forms. They deployed on ascending lines in some cases, and retrogressive lines in others. There were cases of erratic and senile development, reflected

by uncoiling, spiral coiling, and other departures from the normal lines of the order, presaging an episode of " sporting " and retrogression in the next period, to be followed by extinction; but, despite these adverse foreshadowings and some notable reduction in diversity,

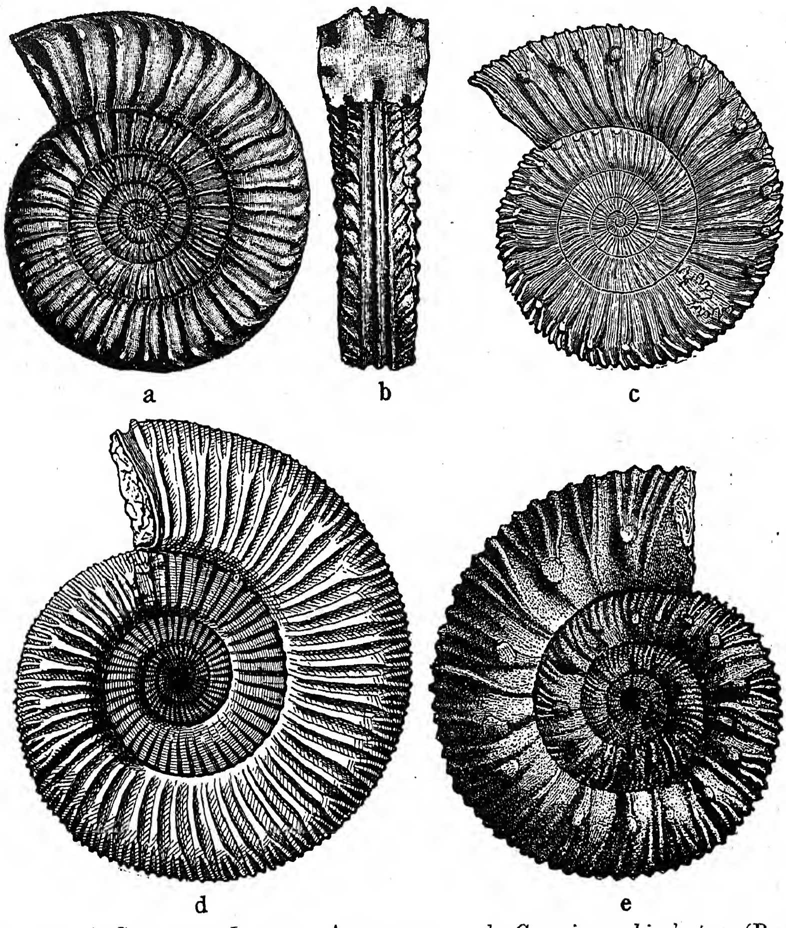


Fig. 357.—A Group of Jurassic Ammonites: *a–b*, *Coroniceras bisulcatum* (Brug.), a lateral and ventral view of one of the *Arietidæ*; *c*, *Deroceras subarmatum* (Young); *d*, *Perisphinctes tiziani* (Oppel); *e*, *Reineckia brancoi* Steinm.

the ammonites were yet in the climacteric stage of their luxuriance and beauty. They had well-nigh reached the limits of attainment in such features as close coiling. complexity of sutures, ornamentation and some other characteristics. The continued expansion of the sea gave them still a widening field over which they spread them-

selves in successive generations with unusual breadth and uniformity, and marked with peculiar fidelity the successive stages of Jurassic marine history. At least thirty faunal zones have thus been distinguished in Europe, and recognized in large degree in southern Asia (Cutch).

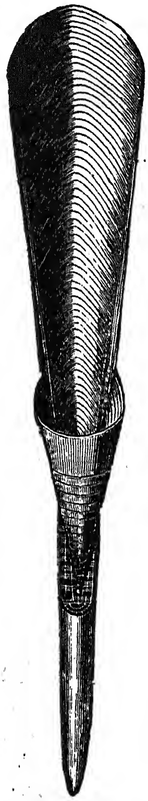


Fig. 358.—The internal shell of a belemnite, restored; the lower, solid, conical portion, the part most frequently preserved, is the rostrum or guard; the middle portion is the phragmocone, which is a diminutive chambered shell with septa, siphuncle, and protoconch as in the older tetrabranch order; the upper part is the prostracum, which corresponds to the "pen" of the living cuttle-fishes.

(2) The ammonites and their predecessors, the ceratites, goniatites and orthoceratites, were tetrabranchs and had external shells, but there had been introduced in the Trias the dibranchiate form which had internal shells, if any at all, and these rose to prominence in the Jurassic with extraordinary rapidity in the form of belemnites. The first known of the cuttlefishes (sepeoids) also appeared at this time. The belemnites were cephalopods of general cuttlefish aspect, usually represented in the fossil state by their internal shell or "pen," as illustrated in Fig. 358. The fact that the phragmocone had the characteristic features of the chambered shells of the tetrabranchiates in a seemingly aborted and useless form, has naturally suggested that the belemnites were their descendents, but this view is not entirely without difficulties. The belemnites rose so rapidly that in the course of the period they almost came to rival the ammonites, and were almost as characteristic of the successive stages of deposition.

(3) The pelecypods also flourished during the period, and took on a markedly modern aspect, the oyster family taking the lead, the *Ostrea* itself being common. Among the more notable genera were the thick-shelled, odd-shaped *Trigonia*, *Gryphæa*, *Exogyra*, and *Ostrea*, and the smooth, thin-shelled *Aucella* of world-wide distribution (Fig. 359). Certain species of *Aucella* were especially characteristic of the northern provinces of both continents.

The gastropods were abundant in some quarters but singularly absent in others, and among them were some genera still living.

(4) Suggestive of shallow clear seas was the reappearance of corals and crinoids in great abundance in the latter part of the period. The modern (*Hexacoralla*) type of corals had come into dominance, and gave rise to reefs so abundant and so wide-spread, particularly in the

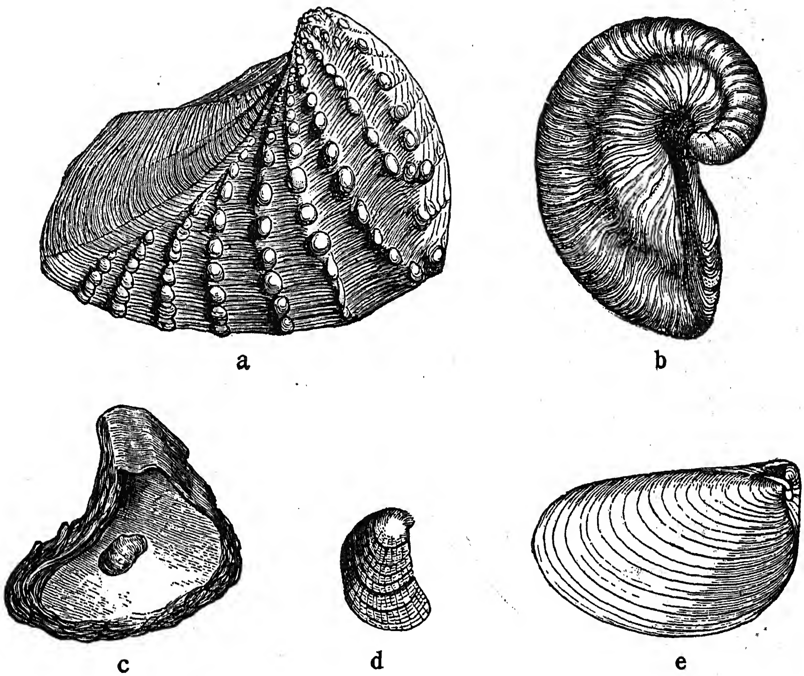


FIG. 359.—A GROUP OF JURASSIC PELECYPODS: *a*, *Trigonia navis* Lam.; *b*, *Gryphœa arcuata* Lam.; *c*, *Ostrea deltoidea* Sby.; *d*, *Exogyra* (*Ostrea*) *virgula* D'Orb.; *e*, *Aucella mosquensis* Keys.

European seas of the Middle Oölitic stage, as to give the name Corallian to the epoch, and Coral Rag to the formation (Fig. 360, *a* and *b*). This was a feature of the last expansive stage of the period, and seems to mark the climax of base-leveled, vegetal-mantled lands, with minimum inwash of silt correlated with a wide, thin sheet of epicontinental water.

The crinoids again rose to prominence, though their diversity of forms was not great. They departed from Paleozoic forms in a marked

diminution of the calyx, and a remarkable extension and subdivision of the arms (Fig. 360, *d*). Unattached crinoids were present. The

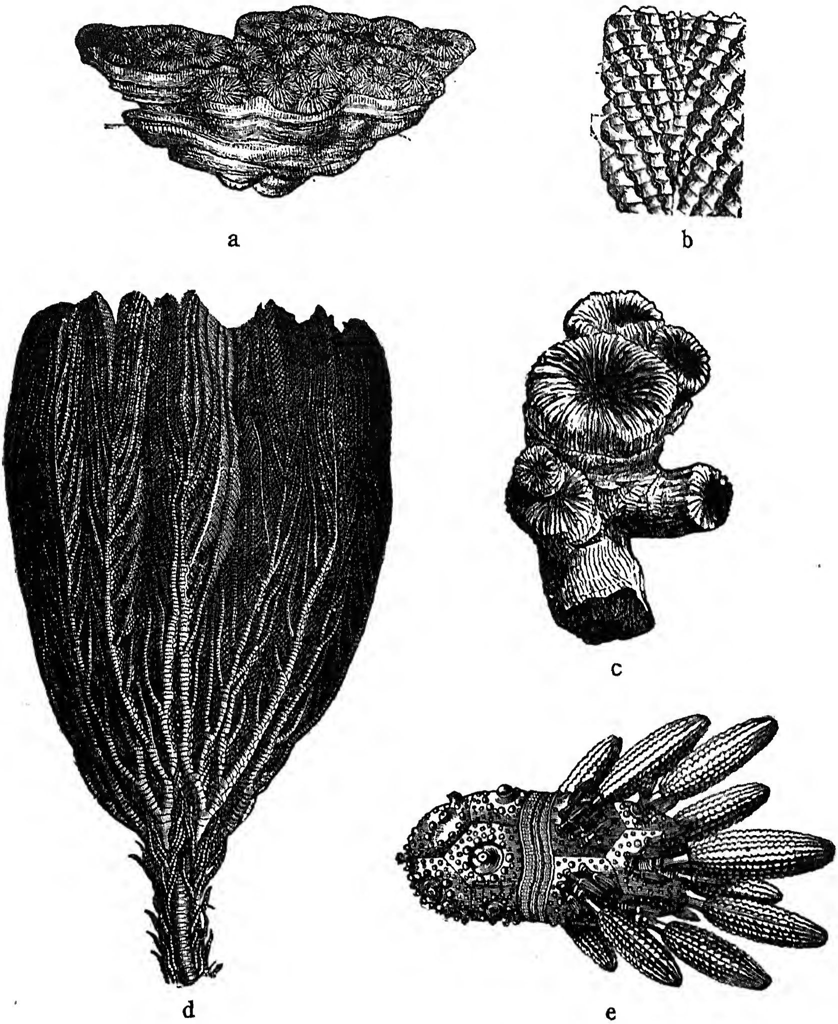


FIG. 360.—JURASSIC CŒLENTERATA AND ECHINODERMATA: *a*, *b*, *Thamnastræa prolifera* Becker, a complete corallum, and the lateral surface of a costal septum enlarged; *c*, *Thecosmilia trichotoma* (Goldf.); *d*, *Pentacrinus briareus* Mill; *e*, *Cidaris coronata* Goldf.

majority of the Jurassic crinoids were undoubtedly shallow-water forms, as most of the Paleozoic types had been; but there is evidence

that deep-water species had begun to appear, leading toward the present dominant but not exclusive habit.

(5) The long, slow evolution of the echinoids in the Paleozoic era was succeeded in the late Trias by the beginning of a rapid and strong evolution in the form of sea-urchins, and these were now on their rapidly ascending curve which reached its climax in the early Tertiary. The Jura was especially rich in the so-called "regular" sea-urchins (*Cidaroida* and *Diadematoida*). The cidarid type, with large club-shaped spines, was characteristic (Fig. 360, *e*).

(6) The crustacean dynasties of the Paleozoic, the trilobites in the sea and the eurypterids in the land waters, now quite extinct, were succeeded by the decapods which rose to a moderate and prolonged ascendency. The prawns and lobsters (*Macroura*, long-tailed decapods) were the earlier division, and the most numerous in the Jura, but the first of the known crabs (*Brachyura*, short-tailed decapods) appeared in this period. The macrourans seem to have especially frequented embayments and protected locations near the land or perhaps within the land, such as are represented in the famous Solenhofen deposit, where terrestrial, fresh-water, and marine forms are preserved in the same sediments. It is not improbable that the macrourans, then as now, had representatives in the terrestrial as well as marine waters.

(7) Sponges were very prolific and well preserved, and give character to the *Spongiten Kalk* of the Upper Jura. Foraminifera flourished and were well preserved, a foreshadowing of their great importance in the Cretaceous period. Radiolarians furnished, by their siliceous tests, the material for the flints that abound in certain parts of the system.

The brachiopods retained the *Terebratula-Rhynchonella* aspect they had assumed in the Trias, but were no longer a leading feature in the fauna except locally.

(8) A marked change in the aspect of the fishes had set in during the Trias, and was continued with further development in the Jura. The crossopterygians and dipnoans were greatly reduced; the selachians continued with undiminished numbers; the skates and rays began their modern career by appearing in two typical families (*Squatinidæ*, Fig. 361, and *Rhinobatidæ*); the *Chimæridæ*, the existing family of sea-cats or spook-fishes, made its appearance and developed notably

(Fig. 362). The forebears of the living gar-pikes and sturgeons took precedence in numbers; the forerunners of the modern *Amia* (Fig. 363,) were an important factor, and the initial forms of the bony fishes (teleosts), the dominant existing type, made their appearance. The peculiar persistent family, *Cœlacanthidæ* (Fig. 364), attained its maximum development. The earliest representatives of the remarkable pycnodonts came in with the early stages of the period. The new aspect was markedly more modern than that presented at the close of the Paleozoic.

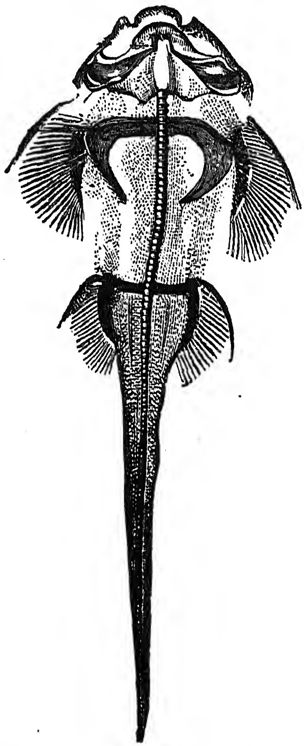


FIG. 361.—A Jurassic skate, *Squatina speciosa*, about two-thirds natural size, from the lithographic stone at Solenhofen, Bavaria. (A. Smith Woodward.)

(9) It was noted under the Trias that certain land-reptiles went down to sea, and introduced a new phase of vertebrate mastery over the deep. From what has just been said of the fishes, it appears that, while doubtless suffering much from the new dynasty, they maintained a notable abundance and variety, and it will be seen later that they outlived the invading race, and resumed their former place of dominance, in large degree, though never wholly.

Marine reptiles.—Of the four groups of reptiles which went down to the sea, the thalattosaurians, ichthyosaurians, plesiosaurians, and thalattosuchians, the first had apparently become wholly extinct, while the last made its first appearance near the close of the period. Of the other two, the ichthyosaurs, as the name implies, were the most fish-like in appearance. They reached their highest development in this period, and from the abundance and wide distribution of their remains, it appears that they were very prolific, and probably traversed every sea. Their adaptation to aquatic life is shown in the complete transformation of the limbs into paddles (Figs. 365 and 366), in the reduction of the outline of the body to ichthyic lines and proportions, in the sharp bending *down* of the vertebræ of the

tail near its extremity for the support of a remarkable caudal fin, in the long snout, set with teeth adapted to seize and hold slipping prey,

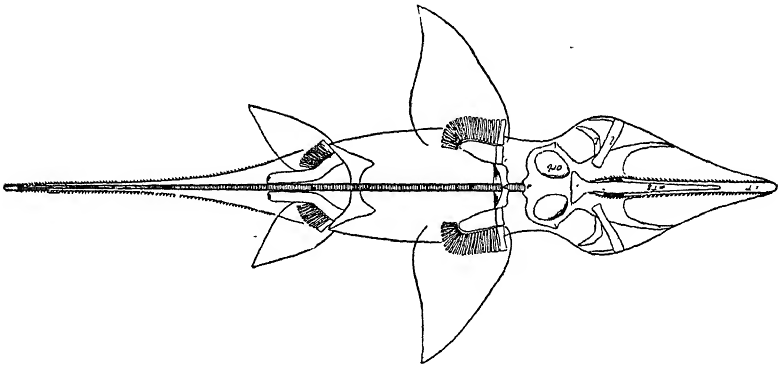


Fig. 362.—A Jurassic spookfish or chimæroid, *Squaloraja polyspondyla*, one-fourth natural size; from the Lower Lias, Dorsetshire. (Restored by A. Smith Woodward.)

but not to masticate it, in the protection of the eye by bony plates, and, interestingly enough, as it would appear from cumulative evidence, in the development of a viviparous habit that freed them from the necessity of returning to land to deposit their eggs, as do the sea-going turtles and crocodiles.

The ichthyosaurs became not a little divergent in form, habit and food, and, in the latter part of the period, developed forms (*Ophthalmosaurus, Baptanodon*) in which the teeth had been greatly reduced in size; some indeed were for a long time supposed to have been quite toothless. That their food consisted in part of invertebrates is evident from the occurrence of the remains of such animals mingled

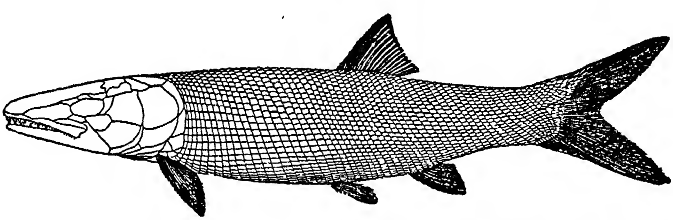


Fig. 363.—A Jurassic forerunner of the modern *Amia*, *Eugnathus athostomus*, about one-seventh natural size, from the Lower Lias, Dorsetshire. (A. Smith Woodward.)

with the fossil contents of the stomach, and it is not unreasonable to suppose their food was largely formed of soft-bodied animals, per-

haps the shelless cephalopods, whose advent has been noticed. The remains of 200 belemnites have been found in a single stomach. There

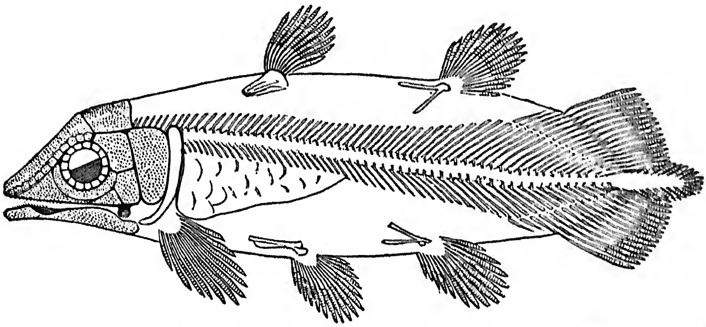


FIG. 364.—A Jurassic cœlacanth, *Undina gulo*, a crossopterygian, about one-seventh natural size; the outline of the air-bladder is shown just back of the gills and under the axis. (Restored by A. Smith Woodward.)

were small as well as large forms of ichthyosaurs, some of the latter reaching 30 feet or more in length.

Descended from a quite different stock, the plesiosaurs adapted themselves to sea life in their own fashion (Fig. 367). Instead of acquiring the flowing lines of a fish, the body took on a form more

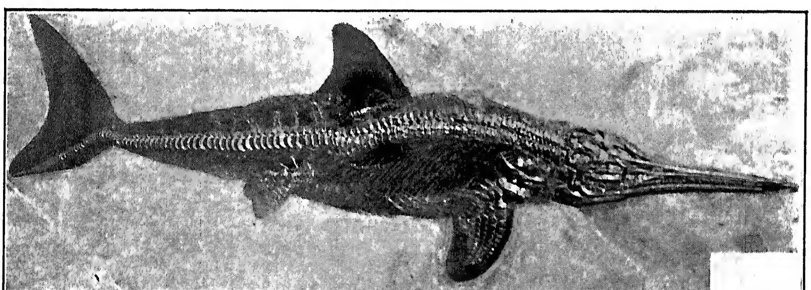


FIG. 365.—Photograph of *Ichthyosaurus quadriscissus* Quenstedt, showing outline of paddles, fins, and body, as well as the skeleton. From the Lias of Würtemberg, from specimen in Carnegie Museum. (Per kindness of Director Holland.)

like that of a turtle, while the neck was very elongate, giving rise to the epigrammatic description "the body of a turtle strung on a snake." The earlier representatives, the nothosaurs, were but partially aquatic, while the true plesiosaurs were wholly so. The limbs of these latter were developed into paddles rather than fins, and were sometimes more than six feet long. Locomotion seems to have been chiefly

dependent on the paddles, though a fin-like adaptation of the tail is sometimes observed. Their movements were hence probably slow. The

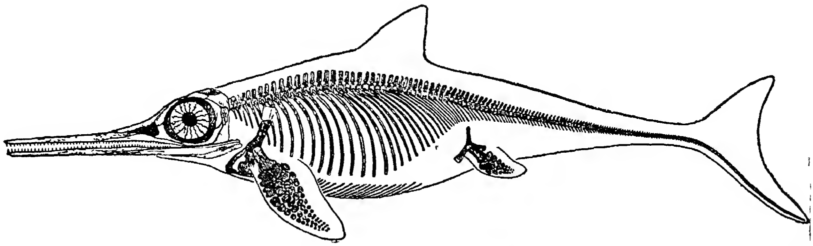


FIG. 366.—Outline and skeleton of *Ichthyosaurus quadriscissus*. (After Jaekel.)

elongation of the neck was variable, some even being short, while the more typical forms were very long. The vertebræ of the neck ranged from 13 to 76, the last being more than any other animal, living or extinct, is known to have possessed (Williston). The neck appears not to have been as flexible as familiar illustrations have represented it, nor were the jaws separable and extensible as in the case of snakes.

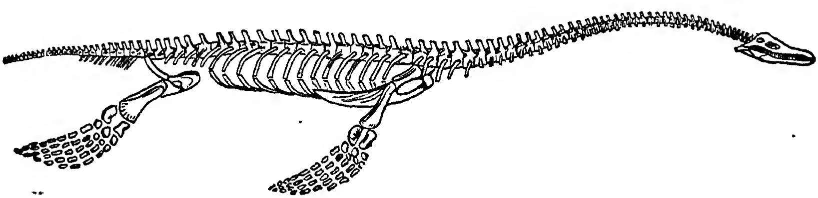


FIG. 367.—Skeleton of *Plesiosaurus dolichodeirus* Conyb. (Restored by Conybeare.)

This implies that they either lived on small prey, or tore their food to pieces before swallowing. They were doubtless formidable foes of the smaller sea life, but probably not of the larger. Like the ichthyosaurs, they were covered with smooth skins unprotected by scales or scutes. They ranged from 8 to 40 or more feet in length. They had the singular habit of swallowing and retaining in the stomach, small stones, "gizzard stones," the purpose of which has given rise to much speculation and discussion. As some of these stones must apparently have been picked up far from the final resting-place of the skeleton, it is inferred that the plesiosaurs were wide rovers of the seas. Williston regards them as solitary in habit, while he thinks the ichthyosaurs were gregarious, somewhat like the dolphin. The distribution of the plesiosaurs seems to have been world-wide, and the species were numerous.

The suborder of crocodilians, to which the name *Thalattosuchia* has recently been applied by Fraas, made its appearance during the latter part of the period, but enjoyed only a brief existence. These truly marine crocodiles had undergone a remarkable adaptation to sea life, from the land or fresh-water forms (Fig. 368). They were very

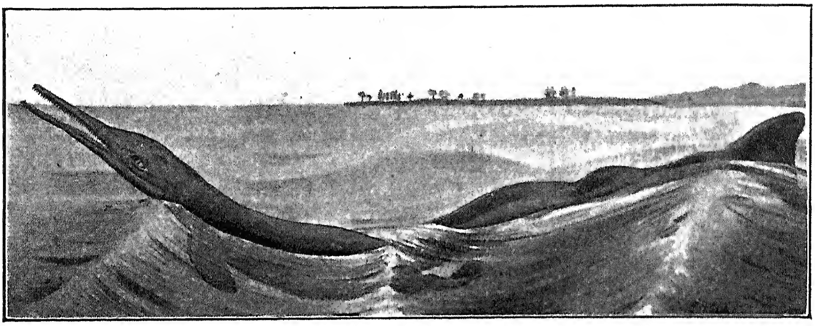


FIG. 368.—Restoration of a Jurassic crocodilian, *Geosaurus suevicus*. (Fraas.)

fish-like in appearance, were wholly covered with a bare skin, and the long tail terminated in a large fin, like that of the ichthyosaurs. The eyes were protected by sclerotic plates, and the fore limbs were short and quite paddle-like. The hind limbs, however, were only slightly modified from the land type, perhaps due to the recurring necessity of visiting the shores for depositing and hatching their eggs.

True marine turtles, so characteristic of the Cretaceous, had not yet appeared, though before the close of the period a number of forms had arisen presenting a strange admixture of characters peculiar to fresh-water and sea turtles (*Thalassemydæ*).

The American marine faunas.—The marine life of Jurassic times is but feebly represented in the American strata, no representatives at all having been found on the eastern coast. There was doubtless a sea-shelf on that border which was occupied by its appropriate fauna, but it has been buried by later deposits.

In the Pacific region, marine life occupied nearly the same districts as in Triassic times, but no consecutive series of faunal evolution has yet been worked out. Present imperfect evidence points to two faunal provinces, one of which succeeded the southern or Nevada-California province of the Trias, and the other the north Pacific province. The fauna of the former ranges from the lower to the upper division, that of the latter represents the later Jura only. The fauna of the earliest epoch (Lias) does not appear to have been derived from

the Triassic fauna which occupied the same region previously. It has the aspect of the European Liassic fauna, and of a similar fauna found in the island of Timor, between Java and Australia, and also in Argentina.

As the successive horizons of the European Jurassic are defined most characteristically by their ammonites,[1] the most instructive element of the fauna of this stage in the Nevada-California-Oregon province was the ammonite family *Arietidæ*, represented by *Arnioceras nevadanum, A. humboldti, A. woodhulli, Coroniceras claytoni,* and *Vermiceras crossmani.* The belemnites are represented by a single form. Several genera of pelecypods were present (*Goniomya, Lima, Pecten, Pinna, Plicatella, Pleuromya,* and *Pholadomya*); a *Turbo* represented the gastropods, a *Cidaris* the echinoderms, and a *Glyphœa* the crustaceans. This list appears very meager when compared with the nearly 250 genera and more than 1600 species enumerated by Etheridge from the corresponding European fauna. How this fauna had communication with central Europe, Timor, and South America is undetermined. A route via the "central Mediterranean Sea" of Neumayr has been suggested,[2] and a route from Timor, via New Zealand and Antarctica to South America, and thence by the coast to California, may be speculatively offered as involving not improbable geographic connections.

The American fauna of the Middle Jurassic epoch is not sufficiently ample, as now known, to clearly indicate its relations to foreign faunas, but it has the aspect of the central European fauna (J. P. Smith). Like the preceding, it is essentially a group of molluscan forms in which the pelecypods greatly outnumber all other species. Several of the preceding genera were present, and several new ones were added (*Modiola, Mytilus, Pinna, Pteroperna, Gervillia, Lima, Ctenostreon, Pecten, Pholadomya, Trigonia, Opis, Inoceramus*). The cephalopods embraced ammonites (*Sphæroceras, Grammoceras,* and *Perisphinctes*) and a belemnite. The gastropods were represented by a large *Nerinea* and the brachiopods by *Terebratula* and *Rhynchonella.*

In the fauna of the Upper Jurassic, the molluscan monotony is relieved by the introduction of several species of corals which are so similar to European species of the Corallian formation as to imply equivalence with that horizon. This is confirmed by the species of pelecypods, by the cephalopod *Rhacophyllites,* and by the gastroped *Chemnitzia.* In other beds of the series, a more considerable group of pelecypods (*Aucella, Avicula, Amusium, Trigonia, Entolium, Oxy-*

[1] "These highly specialized faunas, as has been pointed out by several of the most distinguished paleontologists in Europe, must have been extremely sensitive to the influences of the changes of their surroundings in passing from one geological horizon to another, and have recorded these mutations in their own organizations. Even the encyclopedic Quenstedt continually expresses his satisfaction in turning from the uncertain indications afforded by the more generalized structures of other mollusca to the decisive chronologic evidence usually given by the fossils of this group." Hyatt, Geology of the Taylorville Region, Bull. Geol. Soc. Am , Vol. III, p 404.

[2] For a discussion of this and related subjects see "Mesozoic Changes in Faunal Geography," by James Perrin Smith, Jour Geol., Vol. III, 1895, pp. 369–384.

toma) and of cephalopods (*Cardioceras, Perisphinctes, Olcostephanus, Œcotraustes Reineckia, Macrocephalites*) together with other forms occur.

At a higher horizon there appear significant species of *Aucella* of the types represented by *A. pallasi* and *A. brauni*, associated with *Avicula* and *Amusium*, and the ammonites *Cardioceras* (of the group *C. alterinous*), *Perisphinctes, Olcostephanus*, and *Œcotraustes*, which belong to the northern fauna of Russia (the "boreal" of Neumayr), while the coralline group named above appears to be, allied to the more southern fauna of Europe. From the northern alliance it is inferred that at some time in the closing stages of the Jurassic period, rather free communication was established between the north Eurasian province and the western shore tract of America, and that north Eurasian species migrated down the American coast as far as Mexico, where Nikitin has identified the "boreal" fauna in San Luis Potosi. As the great Jurassic transgression of the sea was especially a northern movement, it is quite consistent that the northern fauna should thus invade the western coast tract of America. The same fauna spread south to the northern side of the Himalayan province, while the fauna of the Cutch region on the Bay of Bengal still retained the central European aspect, as did also that along the east coast of Africa (Mombassa).

The northern and more interior province.—The northern American province, embracing parts of Dakota, Wyoming, and other states (Fig. 348), with northerly connections not yet worked out, bore a fauna of still more pronounced northern affinities. A fine group of ammonites flourished in Wyoming and the Black Hills region (*Cardioceras, Cadoceras, Quenstedioceras*, and *Neumayria*), all of them peculiar to the Callovian and Oxfordian horizons of the upper Jurassic (Hyatt.[1]) The species are not the same as those of the California district, which implies an absence of free inter-communication. Belemnites were well represented (Fig. 369, *c*) and pelecypods (*Ostrea stringileculia* (Fig. 369, *h*), *Camptonetes bellistriatus* (Fig. 369, *d*), *Gryphæa calceola, Tancredia bulbosa, Pecten newberryi, Saxicava jurassica, Mytilus whitei* (Fig. 369, *e*), predominated. Curiously enough, no gastropods have yet been found in this province. The ancient genus *Lingula* (Fig. 369, *j*) had a diminutive representative, as did also the familiar *Rhychonella* (Fig. 369, *i*). A crinoid and a starfish represented the echinoderms.

It is noteworthy that *Aucella*, one of the most characteristic fossils of the California province, has not yet been found in the Dakota province. It is found in Alaska, in the Aleutian Islands, and in Russia. It was formerly supposed that the *Aucella* migrated from Eurasia to America, because, as then known, it ranged lower in Europe; but more recent investigations indicate that it occurred quite as early in America as in Russia, and earlier than in England. If the migrating tract between the Californian province and Asia lay along the Pacific border, while the migrating tract between the Dakota province and Asia lay in the Mackenzie basin and along the Arctic border, the two provinces only coming into free communication far to the westward, it is not difficult to under-

[1] Jura and Trias at Taylorville, California, Bull. Am. Geol. Soc. Am., Vol. III, p. 410.

stand how the *Aucella*, with favoring currents and temperatures, could migrate from California into Russia without migrating into the Dakota province. On the other hand, species migrating from Russia might easily take either the Pacific route to the Californian provinces, or the Arctic-Mackenzie route to the Dakota province. If this were the geographical configuration, future research will probably show that faunas originating on the Pacific coast in America had a distribution like the *Aucella*, and that faunas originating in the Dakota province had a distribution through the Arctic regions and westward into northern Russia,

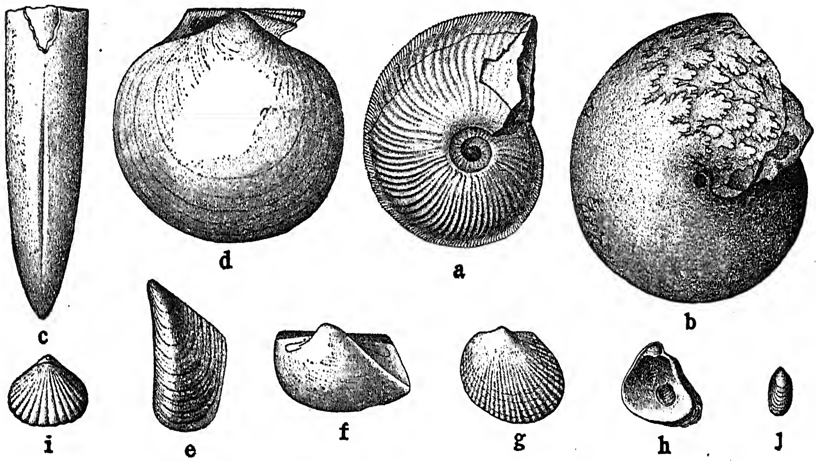


FIG. 369.—CEPHALOPODS: *a*, *Cardioceras cordiformis* M. and H.; *b*, *Neumayria henryi* M and H.; *c*, *Belemnites densus* M. and H. PELECYPODS: *d*, *Camptonectes bellistriatus* Meek; *e*, *Mytilus whitei* Whitf.; *f*, *Grammatodon inornatus* M. and H.; *g*, *Pseudomonotis curta* (Hall); *h*, *Ostrea strigilecula* White. BRACHIOPODS: *i*, *Rhynchonella gnathophora* Meek; *j*, *Lingula brevirostra* M. and H.

rather than into the California province, while Russian forms entered both provinces, and the South Asian forms entered only the Californian province as a rule. In rare cases, species from one American province might reach the other via the junction of their migrating tracts in Asia, or wherever it may have been. At the time of maximum transgression of the sea, more direct communication between the American provinces might naturally have been established. Present knowledge of the Jurassic fauna of the Arctic islands is too scant to throw much light upon this matter. *Ammonites macclintocki*, closely related to *A. concavus*, has been found on Prince Patrick Island, and *A. wosnessenski*, *A. biplex*, *Belemnites paxillosus*, and *Pleuromya unioides* at Cook's Inlet.[1]

The Jurassic fauna of the Dakota province belongs to a late epoch of the period, which implies perhaps that the Arctic sea did not extend its elongate arm so far south until near the time of the great stage of sea transgression of which it constituted one of the striking features.

[1] Dana's Manual, p. 760.

The geographical conception suggested by the distribution of the *Aucella* is perhaps strengthened somewhat by the occurrence of corals in the California province, and their absence from the Dakota province. Neumayr has shown that corals were essentially absent from the northern Russian province, while they abounded in the central and southern European provinces. From this more southerly habitat, their distribution to the Indian province and thence to California, would be consistent with their absence from the Dakota province, if the route along the Pacific sea-shelf were isolated from the Dakota province, as suggested. At the same time, it is not impossible that the former continental tract which connected Asia with Australia and New Zealand, of which there is abundant evidence, may have been extended so as to connect with South America by way of the Antarctic land, from which Australia and South America are separated, respectively, by moderate distances only, and by sea-depths about one third the usual abysmal depths. This would best harmonize with the distribution of the *Arietidæ* from Europe to Timor on the line of the old continental extension between Java and Australia, and thence to the Argentine Republic and to California, where Hyatt finds evidence of their progressive advance from the south to the north. But these suggestions must be held lightly until supported by more evidence.

The Land Life.

I. *The vegetation.*

The land vegetation of the Jurassic was little more than a continuance and enrichment of that of the late Triassic, with slow progress toward living types, cycadeans, conifers, ferns, and equiseta being still the leading forms, slightly more modernized, but not radically changed.[1] The cycadeans (*Bennettitales* and *Cycadales*) were perhaps the most distinctive forms, constituting this the climax of the "age of cycads," but the conifers showed the more notable modernization. They embraced yews, cypresses, arborvitas, and pines, all of which assumed a somewhat familiar aspect, though the species were all ancestral. The ginkgos also played a somewhat important role.

An interesting feature of the European record is the rather frequent occurrence of land plants in marine beds, which not only implies that many trunks, twigs, leaves, and fruit were floated out to sea, but that the landward edges of the deposits escaped serious erosion, a

[1] For a comprehensive paper on the Jurassic plants of the United States, with descriptions and illustrations by Lester F. Ward, see 20th Ann. Rept. U. S. Geol. Surv., 1898–99, pp. 334–430.

phenomenon which grows more common as the deposits become more recent, but is especially characteristic of stages of base-level and advancing seas. It is made the more interesting by the presence, in the same beds, of many land insects that suffered a similar fate. Not a few of them were wood-eating beetles, thus giving a hint of the nature of the battle of life, implying that the plants found enemies not only in wind and storm, but in predaceous foes without and within. In the closing stages, the land was extended, which should in itself have been favorable to an expansional development of plants, but such extensions of the land are so liable to be attended by adverse climatic and topographic changes, that no safe inferences can be drawn except from the actual record, which is rather scanty. In the heart of the period, the distribution of genera and even of species was wide, both in longitude and latitude, implying uniformity of conditions. Some tendency to provincial limitation appears, as in the apparent restriction of *Ptilophyllum* to India, *Gingkodium* to Japan, and the *Abietinæ* to northern Eurasia. The last has been made a basis for the suggestion that a climatic differentiation had begun by the cooling of the northern regions, a suggestion based on the assumption of a universal warm climate in early times, sequent on a molten globe. The flora should probably rather be interpreted as indicating that the period was one of the series of periods marked by the mild, uniform climates attending base-level conditions and sea extension, which *alternated* with periods of more diversified and occasionally severe climates.

II. *The Land Animals.*

Classificatory difficulties.—The discussion of the land animals of the Jurassic Period is embarrassed by a systematic infelicity in the accepted methods of limiting "*Periods.*" Technically, periods are founded essentially on marine formations and marine life; and properly so, because these have given by far the best record, and most closely reflect the deformative movements that lie back of life changes. An ideal marine period consists of a great advance of the sea upon the continent, attended by an expansional evolution of the shallow-water life, followed by a withdrawal of the sea, attended by a restrictional evolution of the life. The ideal division between such periods is obviously the time of maximum withdrawal, when the fauna developed in the expansional stage is being reduced to its lowest terms by restriction,

and the basis of a new fauna is being laid by severe natural selection. But ideally, the expansions and restrictions of the land life are precisely reciprocal to those of sea life, and hence the centers of these normal land periods, are coincident with the dividing points of the marine periods, as illustrated in Fig. 370.

When the land period is very pronounced, as after a great deformative movement, it is apt to be seriously affected by topographic and climatic agencies, and may not be truly expansional in its life evolution, although it may be revolutionary. Such an instance is the Permo-Triassic land period, when aridity and glaciation probably more than offset the increase of land-area in their influence on organic productiveness. But when the deformative movement did not reach such lengths, and a favorable climate and topography accompanied an increase of land-area, there should naturally be an expansional evolution of the land life. At such times also, the mild deformations

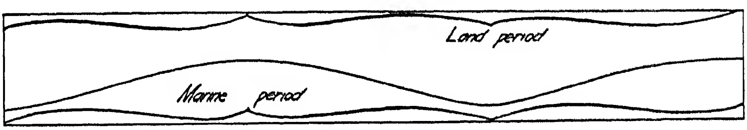


FIG. 370.—A sketch illustrating the reciprocal relations of ideal land periods and sea periods.

should have developed shallow lodgment-basins, and areas of aggradation favorable for a good record of the land life. These theoretical sequences seem to have been realized in the transition from the Jurassic to the Comanchean or Lower Cretaceous. The Purbeckian, usually regarded as the closing stage of the European Jurassic, and the Wealden, usually regarded as the opening stage of the Lower Cretaceous of Europe, though they bridge the dividing line of the marine periods, really constitute together the heart of an important period of terrestrial life development. On the American continent the Como, Trinity, and Lower Potomac horizons stand in the same relations. From this stage dates, as we shall see, the initial deployment of the angiosperms, one of the most important vegetal revolutions in geologic history. In this stage also there was a very marked deployment of the great reptiles. It is inconsistent with a normal treatment of reptilian deployment to dissever it along the lines of division that are most appropriate to the marine life, natural as that is in its own field, and best as a gen-

eral scheme of division. A division at this point is made particularly infelicitous, so far as the land life is concerned, because the American beds of this stage, which are richest in reptilian remains, the Como or Morrison, have usually been referred to the Jurassic (Purbeck epoch). This reference is now questioned, and they are regarded by many, perhaps by most investigators, as Lower Cretaceous (Wealden epoch), while by some, a portion of the beds in question are regarded as Jurassic and the rest as Lower Cretaceous (Comanchean). This adds grave artificial difficulties to the natural ones. It seems best, therefore, to follow the leadings of natural evolution, and to consider the reptilian deployment of the Jura-Comanchean land epoch as an essential unit, with some parenthetical guards against erroneous references.

The Jura-Comanchean development of the land vertebrates. — The anomodonts and some other ancestral reptilian races had followed the stegocephalians into retirement, while other early races lived on in secondary importance. The great feature of the closing Jurassic and opening Comanchean was the marvelous development of the saurian group, which made this the central stage of the " age of reptiles."

The dominance of the dinosaurs.—The dinosaurs in particular attained remarkable size and diversity, and their dominant species were easily lords of the reptile horde. They deployed not only along the carnivorous line (*Theropoda*) which had appeared in the Trias, but also on three herbivorous lines (*Sauropoda, Ornithopoda*, and *Stegosauria*). Of the carnivores, one of the most typical was *Ceratosaurus nasicornis*, from the Como beds, whose general aspect, shown in Fig. 371, illustrates the attitude and proportions of the order. The fore limbs seem to have been used chiefly for seizing and holding prey, and rarely for walking, the animal's pose being facilitated by hollow bones. The head was relatively large, an unusual character for a race among which small heads and diminutive brains were the fashion of the day. Not all the theropods, however, were gigantic; there were small leaping forms, like *Compsognathus*, not larger than a rabbit.

The herbivorous dinosaurs (*Stegosauria, Sauropoda, Ornithopoda*[1]) first became known in this system, but their development was so ex-

[1] For monographic treatment see Dinosaurs of North America, O. C. Marsh, 16th Ann. Rept., U. S. Geol. Surv. The three suborders there recognized are *Theropoda*, *Sauropoda*, and *Predentata*, *Ornithopoda* and *Stegosauria* being regarded as divisions of *Predentata*.

traordinary that they soon outranked the carnivorous forms both in size and diversity. The sauropoda were generally massive animals, with sub-equal limbs and the quadruped habit. Among these, *Brontosaurus* (*Apatosaurus*) attained the extraordinary length of 60 feet

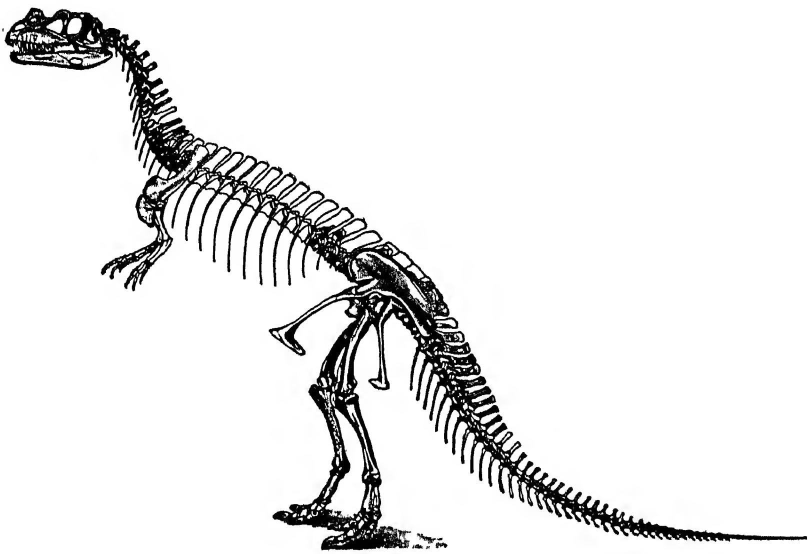


FIG. 371.—A carnivorous dinosaur, *Ceratosaurus nasicornis*, about $\frac{1}{40}$ natural size, i.e. length about 17 feet; from the Como beds, Colorado. (Restoration of skeleton by Marsh.)

and possibly more, taking rank as one of the largest of known land animals (Fig. 372). This enormous creature was characterized, nevertheless, by weakness rather than strength. The general organization was unwieldy; the head was very small relatively, the brain having less diameter than the spinal cord. "The task of providing food for so large a body must have been a severe tax on so small a head." The inconvenience of its bulkiness was perhaps relieved by an aquatic habit. From the fact that its skeleton is sometimes found in a nearly complete and orderly state, it has been inferred that the creature was not infrequently the victim of its own massiveness, and lost its life by sinking in some soft, treacherous shoal. This colossal animal may be taken as illustrating the point at which bulk becomes a burden, and as signalizing an approach to the limit of evolution in the line of size. Even larger than *Brontosaurus*, and the largest of all known dinosaurs, was *Brachiosaurus*, of which the femur measured more than two meters

in length ($80\frac{1}{2}$ inches).[1] There were several other genera of similar nature and of bulk only inferior to these monsters. The tribe was most abundant and most specialized in America, which was doubtless its place of origin; but some European forms (notably *Cetiosaurus* of England) were so closely related as to be regarded by some as generically identical.

The typical ornithopod (bird-footed) dinosaurs were bipedal in habit, much as the carnivores were. On the hind limbs there were usually only three functional toes, so that they left a bird-like track; the fore limbs, however, had five digits. *Camptosaurus*, known both from America (Morrison beds) and Europe, and nearly related to the European *Iguanodon* of the Wealden, was one of the largest of the ornithopod dinosaurs, measuring about 30 feet in length, and about 18 in height, in the walking posture. Other related forms, like *Nanosaurus* or *Laosaurus*, were not more than three or four feet in height and were the smallest of this group known.

The stegosaurs, like the sauropods, were quadrupedal in habit, and, like them, had solid bones. They were curiously armored, and formed a group of very remarkable creatures that frequented England

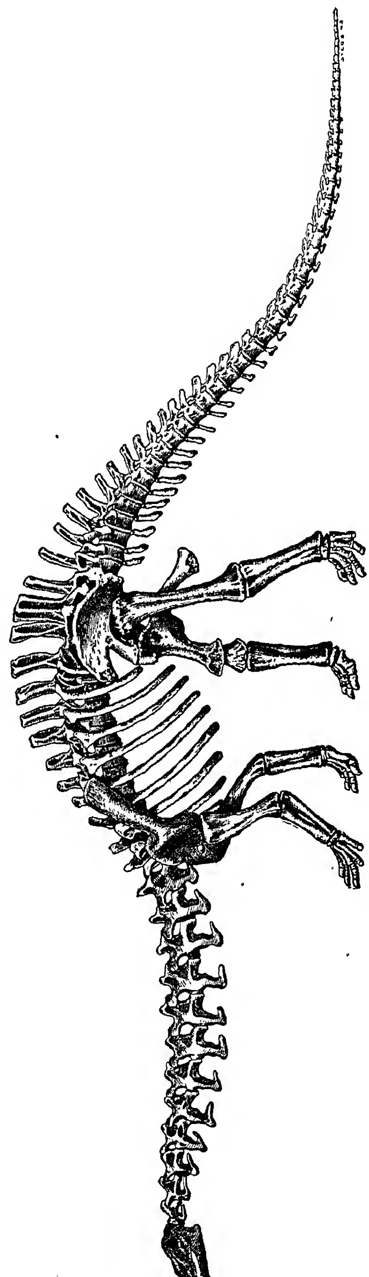


FIG. 372.—An herbivorous dinosaur, *Brontosaurus* (*Apatosaurus*). Restoration of skeleton by Riggs, nearly 60 feet long; from Wyoming.

[1] Riggs, Amer. Jour. Sci., 1903.

and western America. While they were less gigantic than the sauropods, they found compensation in protective plates, spines, and similar modes of defense. The *Stegosaurus* of Colorado and Wyoming (Como beds) was one of the most unique, (Fig. 373.) The remarkably diminu

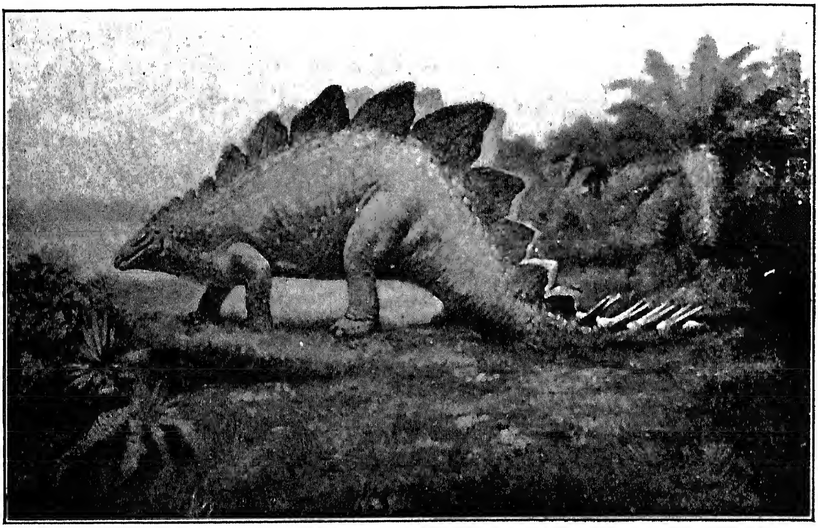


FIG. 373.—*Stegosaurus*, an armored dinosaur of the Jurassic. Interpreted by Charles R. Knight. (Lucas' Animals of the Past. By permission of the publishers, Messrs. McClure, Phillips and Company.)

tive head and small brain imply a sluggish, stupid beast, depending for protection on its bulk and armor.

The prevalence of so many of these dinosaurs on the North American and the Eurasian continents seems to imply that these lands were connected, and that they were the chief dinosaurian home, though dinosaurs have been identified in South Africa in beds probably Triassic.[1]

Other reptilians.—The true rhynchocephalians first made their appearance during the Jurassic, in forms scarcely distinguishable from the living *Sphenodon*, but they played no conspicuous role. Turtles became abundant, though distinctively marine forms had not yet appeared. The crocodilians, though still retaining the primitive type of biconcave vertebræ, became differentiated into the marine thalattosuchians, the long-headed, gavial-like teleosaurs, and the short-headed, crocodile-like types which probably found much of their

[1] Broom, The Geology of Cape Colony, by A. W. Rogers, 1905, p. 244.

food in the small mammals and reptiles frequenting the shores of the estuaries. Primitive lizards were doubtless abundant, but because of their terrestrial habits and small size, very few if any have been discovered.

The advent of aërial life; the pterosaurs.—It has already been noted that the crowding of the land may have led some reptiles to take to the sea. The same influence may have forced others to take to the air, and thereby escape the monsters of the swamps, jungles, and forests. Whatever the cause, the most unique feature of the period was the development of flying reptiles. Appearing at the very close of the Trias in a few yet imperfectly known forms, they presented themselves at the very opening of the Jurassic period (Lower Lias), as fully developed flying animals in the genus *Dimorphodon*, and later formed a diversified group embracing long-tailed forms, as

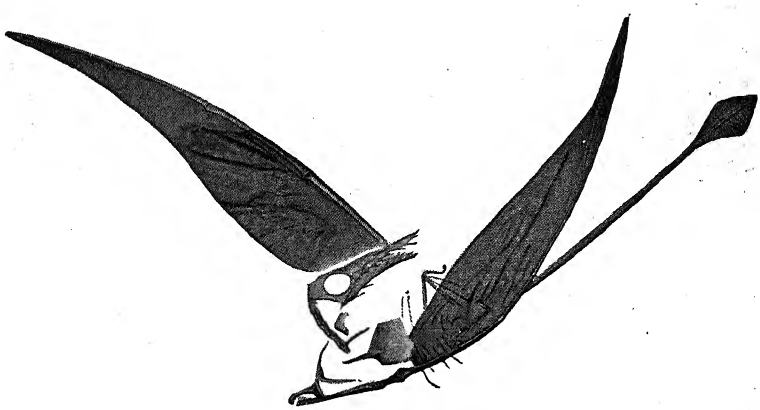


FIG. 374.—A flying saurian, *Rhamphorhynchus phyllurus* Marsh, in which the wing membranes are preserved; about one-fourth natural size. The rod-like bones that support the wing membranes are the extended fifth phalanges; the caudal oar and the elongate skull are also well shown. From the lithographic stone at Eichstadt, Bavaria.

Rhamphorhynchus, and short-tailed forms, as *Pterodactylus*. With little doubt they sprang from some agile, hollow-boned saurian, more or less remotely akin to the slender, leaping dinosaurs. Between the ponderous brontosaurs (Fig. 372) and the airy pterodactyls (Fig. 374), the Jurassic suarians present the strangest of contrasts. The Jurassic pterosaurs were small, but their successors attained a wing-spread of nearly a score of feet. They were curiously composite in structure and adaptation. Their bones were hollow, their fore limbs modified

for flight, their heads bird-like, and their jaws set with teeth; but toothless forms at length appeared. They were not adorned with feathers, but provided with membranes stretched, in bat-like fashion, from the fore limbs to the body and hinder limbs, and serving as organs of flight (see Fig. 375). The fifth, or as some paleontologists believe, the fourth, digit was greatly extended, and served as the chief support for the wing membrane. The sternum was greatly developed, implying that they had true powers of flight, a conclusion supported by the occurrence of their remains in marine sediments free from land relics, indicating burial far out to sea. They had a singu-

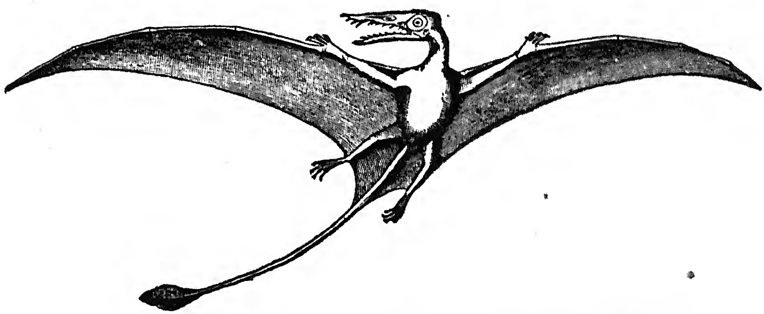


FIG. 375.—*Rhamphorynchus phyllurus.* (Restored by Marsh.)

larly elongated rod-like tail, with a rudder-like expansion at the end (Fig. 375).

The pterodactyls (Fig. 376) had short tails, and were usually small and slender. Fully differentiated as first found, the pterosaurs underwent no radical change of structure during their career, and the steps of their remarkable evolution are for the most part unknown.

The appearance of true birds.—A less bizarre, but really greater evolution, was the contemporaneous differentiation of true birds, which appeared in a similarly advanced state of development. The ancestors of the pterosaurs and the birds may doubtless have been closely allied far back toward the point of common saurian or stegocephalian divergence, but there is no evidence whatever that the pterosaurs developed into true birds. The two are types of analogous and parallel evolution, and not of successive relationship. The earliest known bird, *Archæopteryx macrura* (Fig. 377), shows an advanced state of evolution, and at the same time clear traces of reptilian ancestry. From this

ancestry it retained a long, vertebrated tail, reptile-like claws, and fore limbs, teeth set in sockets, biconcave vertebræ, and separate pelvic bones. On the other hand, its head and brain were bird-like, its anterior limbs adapted to flying in bird fashion, not in pterosaurian fashion, its posterior limbs modified for bird-like walking, and most distinctive of all, it was clothed with feathers. The perfect development of the feathers, while yet the body retained so many reptilian features, is most notable. But for their fortunate preservation, it is uncertain whether the creature would have been classed as bird or

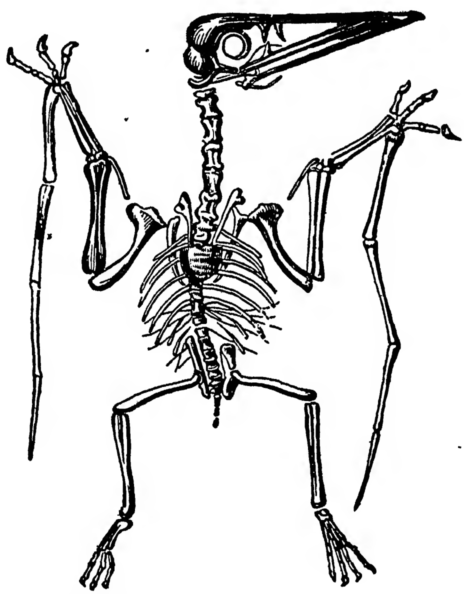


FIG. 376.—A pterodactyl, *Pterodactylus spectabilis*, from the lighographic stone at Eichstadt, Bavaria, about three-fourths natural size. (After H. v. Meyer.)

reptile. The known species was somewhat under the size of a crow. Two skeletons and a single isolated feather found in the lithographic quarries of Bavaria, are the only relics yet recovered from the Upper Jurassic beds.

The non-placental mammals.—The marvelous deployment of aquatic and terrestrial reptiles, of pterosaurs and birds, makes the scanty record of the mammals all the more singular. Only a few jaws of the size of those of mice and rats have been found either in America or in Europe (Fig. 378). These low types are referred, without complete

certainty, to the marsupial order. They appear to have been insectivorous. No certain evidences of placental mammals have been found.

The insects.—The insects appear to have included members of

FIG. 377.—The earliest known bird, *Archæopteryx macrura.* The long vertebrated tail, the clawed digits of fore limbs, and the toothed jaws are ancestral features to be specially noted. (H. v. Meyer.)

nearly all the fossilizable groups that were not dependent on the angiospermous plants, directly or indirectly. As before, the neuropterous and orthopterous orders predominated, the former represented by well-formed dragon-flies, in addition to may-flies and termites; the

latter by cockroaches, crickets, etc. To these were added many beetles of several different families, some *Hemiptera*, the earliest known

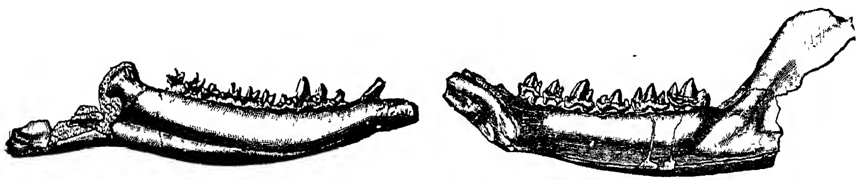


FIG. 378.—Lower jaws of American non-placental (polyprotodont) mammals of the Upper Jurassic. *a*, *Priacodon ferox;* *b*, *Dryolestes vorax*. One and one-half times natural size. (After Marsh.)

Diptera, represented by flies, and the earliest known *Hymenoptera*, represented by ants; but the *Lepidoptera* (butterflies and moths) were yet awaiting the appearance of the flowering plants.

Little that is new relative to the life of the fresh waters is revealed by the Jurassic strata.

CHAPTER XIV.

THE COMANCHEAN (LOWER CRETACEOUS) PERIOD.[1]

Introductory.

AT the close of the Jurassic period, large areas in the western part of North America which had been submerged became land, and at the beginning of the succeeding period, the larger part of the North American continent was above sea-level. The history of the Cretaceous period, as that term has commonly been used, is rather complex. The general sequence of events in North America is somewhat as follows: (1) Early in the period there was a somewhat widespread warping of the continental surface, resulting in sedimentation at many points within the continental borders. Submergence was extensive in Mexico and Texas, and the sea extended thence as far north as the Ouachita Mountains, and temporarily beyond, while on the Pacific coast a narrow border of the present land was beneath the sea. Along the Atlantic and Gulf coasts, and in some parts of the western interior, considerable tracts were brought so low, or into such an attitude, as to become the sites of deposition, though not submerged beneath the sea. A prolonged period of sedimentation followed these geographic changes. (2) This period of sedimentation was followed by an interval when most of the areas which had recently been the sites of deposition, whether marine or non-marine, were exposed to subaërial degradation. (3) After this interval had been sufficiently long to allow of very considerable erosion of the Early Cretaceous beds, the sea encroached upon the Atlantic and Gulf borders, covering, and in general spreading beyond, the non-marine formations of the earlier stage. It again covered Texas, and presently extended northward over the Great Plains to the Arctic Ocean, forming a great

[1] For a full review of the American Cretaceous, up to 1891, see White (C. A.) Bull. 82, U. S. Geol. Surv.

mediterranean sea several hundred miles wide from the mouth of the Mackenzie River on the north, to the mouth of the Rio Grande on the south, dividing the continent into two unequal parts, a larger eastern, and a smaller western. On the Pacific coast also, the sea extended its area somewhat at the expense of the land. There have been few greater incursions of the sea over the land, and therefore few equally great geographic changes, during the long history of the North American continent. A long period of deposition was initiated by the submergence, and this was succeeded in turn by (4) a widespread withdrawal of the waters. The mediterranean sea disappeared, and the borders of the land were extended seaward on the east, the south and the west, and the continent became nearly or quite as large as now.

The formations of the Cretaceous system are commonly divided into two main series, the Lower and Upper. To the former are referred the deposits of the earlier and lesser submergence, and to the latter, those of the later and more extensive submergence. The distinctness of the Lower and Upper Cretaceous is however so great that it seems, on the whole, in keeping with the spirit of the classification here adopted, to regard the two series as separate systems, and the corresponding divisions of time as separate periods. From the physical standpoint, the distinction between the Upper and Lower Cretaceous is greater than that between the different parts of any Paleozoic system, as commonly classified, if the Mississippian and the Pennsylvanian be regarded as separate systems, and greater than that between the Cambrian and the Ordovician, or between the Devonian and Mississippian. The paleontological phase of the question is discussed elsewhere. If the Lower Cretaceous be separated from the Upper, it may be called the Comanchean or Shastan system.[1] The propriety of this classification becomes the more striking, since it is equally applicable to other continents.

This classification involves no new idea. Hill, who has made a special study of the North American Cretaceous where both the Lower and Upper systems are developed, has repeatedly emphasized their distinctness,[1] and Neumayr,[2] after reviewing the relevant evidence

[1] The first of these terms has been applied to the Lower Cretaceous of Texas (Hill), and the second, by Le Conte and others, to the Lower Cretaceous of California.

[2] See references to his papers in the following pages.

[3] Erdegeschichte Bd. II, p. 377.

drawn chiefly from the phenomena of the old world, concludes that if the distinctness of the Lower and Upper Cretaceous had been known when the accepted time-divisions were established, they would have been made separate divisions of equal rank with the Triassic, Jurassic, etc. The Lower and Upper Cretaceous are therefore here considered as two somewhat closely associated periods, coördinate with the Triassic and Jurassic.

The following table (p. 109) gives some idea of the relations of the two systems, and of their parts, though the correlations for different regions are not to be regarded as exact.

The Comanchean (Shastan, Lower Cretaceous) System.[1]

The warping which marked the opening of the Comanchean period occasioned the development of extensive lakes or other basins of non-marine deposition in some parts of the continent, while other parts were depressed beneath the sea. The Comanchean deposits of the Atlantic and Eastern-Gulf coastal plains, and in certain parts of the western interior, are non-marine; those of the western Gulf region, extending as far north as the Ouachita Mountains and even a little beyond, are chiefly marine, while those of the Pacific coast are wholly so. From the distribution of the marine strata of the system, it is clear that by far the larger part of the continent was above sea level during the period, unless the deposits have been extensively removed by erosion, and this does not appear to be the case.

The Atlantic and Gulf Border Regions.

To understand the relations of the Cretaceous on the Atlantic coast,[2] it should be recalled that during most of the Paleozoic era, the area east of the Appalachians, as far as the present coast and beyond, was land, and that when the Appalachians came into existence at the close of the Paleozoic, some parts of Appalachia were bowed or broken so as to become the sites of deposition, and here the Triassic

[1] For an excellent summary of the Lower Cretaceous, see Stanton's Lower Cretaceous Formations and Faunas, Jour. of Geol., Vol. V, 1897, pp. 579-610. As the title implies, this paper deals with paleontological, rather than physical questions. Full bibliography.

[2] Data concerning the Lower Cretaceous formations of the Atlantic coast are to be found in reports of the Geological Surveys of New Jersey and Maryland (Vol. I). See also McGee, article cited below.

	Atlantic Coast.	Eastern Gulf Region.	Western Gulf Region	Western Interior.	Pacific Coast.	European.
(Upper) Cretaceous.	Manasquan Rancocas	Wanting	Wanting	Denver, Livingston, etc. (Perhaps Eocene) Laramie	Wanting or not differentiated	Danian
	Monmouth Matawan	Ripley Selma Eutaw	Montana series Navarro	Montana series 2. Fox Hills 1. Fort Pierre and Belly River	Chico	Senonian
			Colorado series 2. Austin 1. Eagle Ford	Colorado series 2. Niobrara 1. Benton		Turonian
	Wanting	Wanting	Dakota Woodbine	Dakota		Cenomanian
Comanchean. (Lower Cretaceous).	Unconformity	Unconformity	Unconformity	Unconformity	Unconformity	Albian Unconformity in places Aptian
			Washita		Horsetown	Urgonian
		Tuscaloosa series	Fredericksburg	Kootenay and Morrison (or Como)	Knoxville	Neocomian Wealden
	Potomac series 4. Raritan 3. Patapsco 2. Arundel } Jurassic? 1. Patuxent }		Trinity			

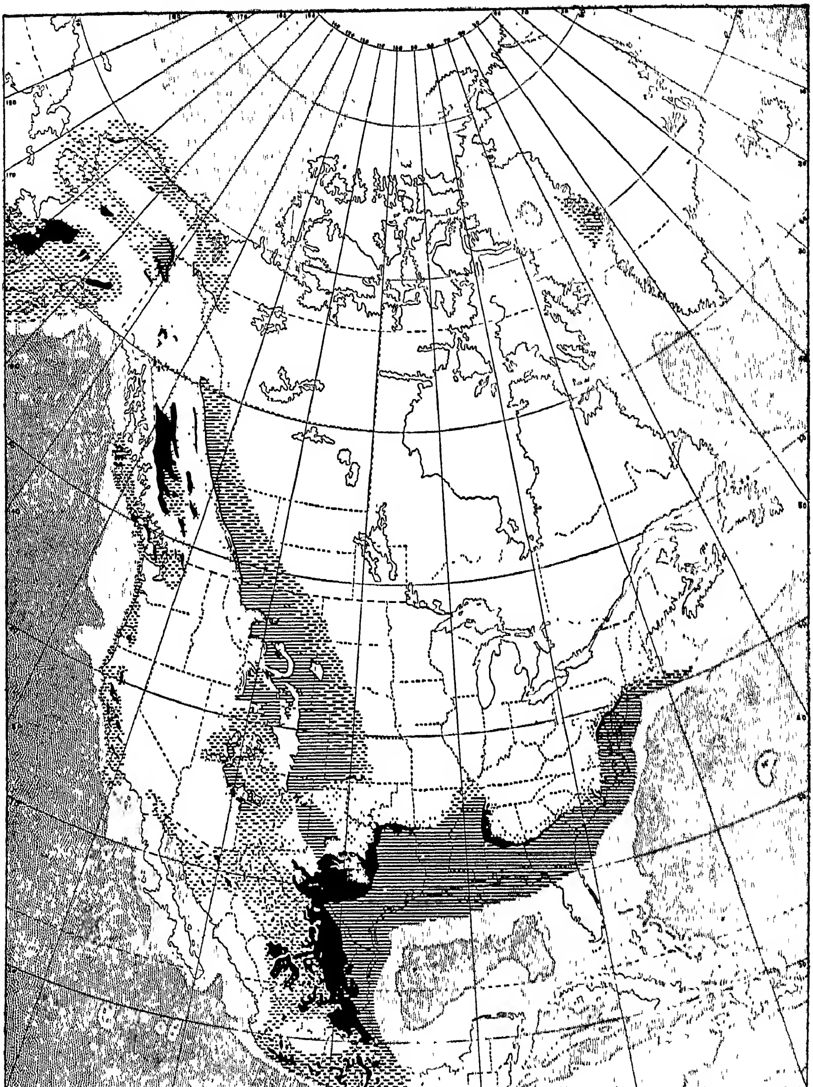


FIG. 379.—Map showing the distribution of the Comanchean formations in North America. The conventions are the same as in preceding maps.

beds of the Atlantic province were laid down (p. 1). The sedimentation was attended and followed by igneous intrusions, and probably by faulting and warping. At the close of the Triassic period, as nearly as now known, the surface was again deformed, and a period of erosion which lasted through the Jurassic period inaugurated. By the beginning of the Comanchean period, both the Appalachian Mountains and the area of the present Piedmont plateau had been degraded well toward base-level.[1] Little warping of the surface therefore appears to have been needed to convert portions of the coastal lands into sites of sedimentation. That part of the Comanchean (Lower Cretaceous) system which is found along the Atlantic coast is called the *Potomac*[2] series. The formations tentatively referred to the Jurassic[3] are generally included in this series. Other names have local application (see table above).

The conditions of sedimentation along the eastern part of the Gulf coast appear to have been similar to those along the Atlantic, and the corresponding formations constitute the *Tuscaloosa*[4] series.

The approximate surface distribution of the Potomac and Tuscaloosa series is shown on the accompanying map (Fig. 379), from which it is seen that they are not traceable into each other at the surface; but there is general agreement that they were, at least in part, contemporaneous. Neither is believed to represent the whole of the Comanchean system as developed elsewhere. On the basis of fossils, the Tuscaloosa is thought to represent only the latter part of the time when the Potomac was in process of deposition, while both are referred to the early rather than the late part of the period. If both are referable to the earlier part of the Comanchean period, it is not now possible to say how far this is to be accounted for by the emergence of the regions where the series occur before the later part of the period,

[1] The possible Jurassic beds of the Atlantic coast (p. 59) are not brought into consideration here.

[2] McGee, Am. Jour. Sci., Vol. XXXV, 1888, pp. 120–143; Clark and Bibbins, The Stratigraphy of the Potomac Group in Maryland, Jour. of Geol., Vol. V, 1897. pp. 479–506. This article treats of the Potomac as a whole; also Bull. Geol. Soc. Am., Vol. XIII, pp. 187–214, 1902.

[3] Marsh thought the whole Potomac series Jurassic, Am. Jour. Sci., Vol. II, 1896, pp. 433–477.

[4] Smith and Johnson, Bull. 43, U. S. Geol. Surv., 1887. For a better and later summary of the Tuscaloosa of Ala., see Smith, Geol. Surv. Ala , 1894.

and how far the result of the removal of the later beds by erosion. The unconformity between this series and the (Upper) Cretaceous above shows that erosion removed some of the former, before the deposition of the latter.

Constitution and structure of the Potomac and Tuscaloosa series.— In its mode of formation the Potomac series appears to belong to the less familiar of the two great classes of deposits, the *terrestrial*, as distinguished from the *marine*. As already noted, the whole eastern mountain and plateau region seems to have suffered peneplanation during the Jurassic period, attended inevitably by the deep decay of the underlying crystalline and other rocks, and the consequent accumulation of a heavy mantle of residuary earth and insoluble rock. The warping which inaugurated the Comanchean period seems to have involved a rise of the axis of the Appalachian tract, and a consequent rejuvenation of the drainage from it, while the coastward tract was left relatively flat, or perhaps bowed into a concave attitude, making it a zone of lodgment for the sediments brought down from the west. The quickened drainage of the axial tract, acting on material prepared for easy removal, loaded itself with a burden it could not carry across the low coastal tract, and deposition resulted. It is perhaps not necessary to assign concavity or permanent submergence to the lodgment tract, if the loading of the rejuvenated head-waters of the streams was sufficient; but lakes, marshes, etc., were probably features of the area. These conditions are in harmony with the constitution of the deposits, which consist of gravel (or conglomerate), sand (or sandstone), and clay.

The gravel (or conglomerate) at any point is made up principally of materials derived from the formations adjacent on the west, and subordinately from the subjacent formations. It is often arkose in the immediate vicinity of the feldspar-bearing crystalline rocks, but elsewhere it is composed chiefly of the resistant products of mature weathering. Among these, quartz, from the quartz veins of the crystalline rocks is often conspicuous. Chert, quartzite, and sandstone from the Appalachians, are also constituents. The gravels are sometimes disposed irregularly, constituting lenses or beds of varying thickness.

The sands are sometimes fine and the grains well rounded, as if long transported by moving water, and sometimes coarse and angular, as if they had been subjected to but little wear. Like the gravel,

the sand-beds are sometimes rather lawless in their disposition. Locally the sand contains feldspar grains, or bits of kaolin which have resulted from their decay. The presence of the feldspar (or kaolin) in the sand, like the presence of pieces of schist in the gravel, shows that erosion sometimes exceeded rock decay. This betokens high land to the west whence the sediments were derived, and is one of the reasons for the belief that the region west of the site of deposition was tilted upward at this time.

Much of the feldspar of the crystalline rocks was already decomposed at the time of the Potomac sedimentation, and the resulting clay was often separated, in deposition, from the coarser grains of quartz. This separation was the work of the waters which transported the detritus, and while it was effected by physical means, and for physical reasons, it resulted in the separation of materials which were chemically unlike. The separation was by no means always complete; but it went sufficiently far to give rise to beds of clay of such purity and magnitude that they have been extensively utilized (especially in New Jersey[1]) for the manufacture of clay wares. The beds of clay, like those of gravel and sand, are sometimes in the form of huge lenses. The clay often shows little trace of stratification, and is notable for its bright and variegated colors, black, white, yellow, purple, and red being not uncommon. White is to be looked upon as the normal color; the others are the result of various impurities, the blackness being due to organic matter.

The irregular disposition of the clay, sand, and gravel is doubtless the result of the physical conditions where the sedimentation took place. On an exposed coast, the waves and littoral currents tend to spread the coarse sediment along the shore, while the finer sediments are carried farther out. Where the Potomac sediments were deposited, such processes appear not to have been effective, and the sediments vary notably from point to point. Their disposition is often such as to suggest that they were deposited along the lower courses of rivers or at their debouchures, where shore-waters had little effect upon them. On the other hand, the perfect separation of the sand from the clay in many places, points to the existence of

[1] Cook, Geol. Surv. of New Jersey, Report on Clays (1870), and Kümmel, Ries, and Knapp, 1904.

local conditions which allowed of the differentiation of sediments to an unusual degree. This differentiation may have been effected in large part by land drainage. If marshes, lagoons, and small isolated bodies of water were the sites of deposition, and if the contributing streams were of varying velocities, and therefore bearing loads of various grades of coarseness, some of the peculiarities of structure would find their explanation. Slight oscillations of level, or slight shiftings of the debouchures of the streams may have caused the deposits of separate streams to become continuous. Similar results might have been brought about if the conditions were estuarine. If this was the case, there must have been a barrier to the east, shutting out the sea, and of such a barrier there is some evidence.[1]

In addition to the clastic sediment, there is a little lignite, and some iron ore, and though both are widely distributed, neither is of much commercial value. Both formations are natural results of the conditions assigned. Amber has been found in the series at several points, though in small quantities only.[2]

The Tuscaloosa series is like the Potomac in general constitution, though gravel is, on the whole, less important. Clay predominates in the lower portion, and sand in the upper. The bright colors and the irregular stratigraphy characteristic of the Potomac are also characteristic of the Tuscaloosa series.

The Potomac, as already implied, is a series of formations, rather than a single formation. Even if the lowermost part of the series heretofore called by this name proves to be Jurassic, the portion above is not a unit. In Maryland[3] two distinct formations (the Patapsco and the Raritan) have been recognized within it, the one unconformable on the other. A similar subdivision has not been established for the series farther south.

Stratigraphic relations.—Along the Atlantic Coast the Potomac series rests unconformably on the Triassic (New Jersey) and pre-Cambrian (Pennsylvania and south) formations. Its general stratigraphic relations are shown in Fig. 380. The Tuscaloosa series rests on crystalline schists (pre-Cambrian) at the east, but farther west on

[1] Clark and Bibbins, Bull. Geol. Soc. of Am., Vol. XIII, pp. 209-12.

[2] Hollick, Am. Nat., Vol. XXXIX, 1905.

[3] Clark, Jour. of Geol., Vol. V, 1897, pp. 479-506; also Maryland Geol. Surv., Vol I, pp. 191-2.

Paleozoic strata. Both the Potomac and Tuscaloosa are overlain unconformably by the Upper Cretaceous beds.

Thickness.—The Potomac series rarely reaches a thickness of 700 feet, while the thickness of the Tuscaloosa series in Georgia, Alabama, and Mississippi reaches 1000 to 1500 feet.

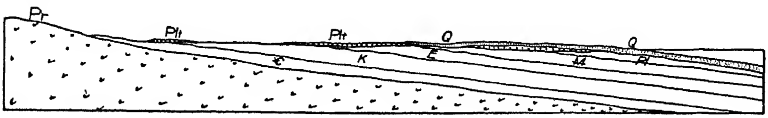


FIG. 380.—Section showing relations of various members of the Coastal series. *C*, Comanchean; *K*, Cretaceous; *E*, Eocene; *M*, Miocene; *Pl*, Pliocene; *Q*, Quaternary.

The Texas Region.[1]

The Lower Cretaceous system is much more fully represented in Texas than farther east and north, but its stratigraphic relations are the same. The beds appear at the surface over an area distant from the coast (Fig. 380), dip seaward at a low angle, and are concealed near the coast by younger formations.

The Comanchean system of Texas embraces three distinct series. The oldest was perhaps contemporaneous with the Potomac series, but the youngest is probably younger than any part of the series of the Atlantic Coast. The system is much thicker in Texas than farther east, ranging from 1000 to about 4000 feet, the slighter thickness being to the northeast, and the greater to the southwest. In Mexico, these thicknesses are greatly exceeded.

The three series of the Comanchean system, commencing below, are (1) the Trinity, (2) the Fredericksburg, and (3) the Washita.

[1] Present knowledge of the Cretaceous in this region is due largely to the work of R. T. Hill. The latest account published is in the 21st Ann. Rept. U. S. Geol. Surv., Pt VII. An earlier paper, *Geology of Parts of Texas, Indian Territory and Arkansas adjacent to the Red River*, Bull. Geol. Soc Am , Vol. V, 1893, pp. 297–338, contains a list of the author's other papers, the more important of which, from the present point of view, are the following: *The Texas Section of the American Cretaceous*, Am. Jour. of Sci., Vol. 34, 1887; *The Topography of the Cross Timbers and Surrounding Regions of Northern Texas*, Idem, Vol. 33, 1887; *Description of the Cretaceous Rocks of Texas and their Economic Value*, First Ann. Rept. Geol. Surv. of Texas, 1888; *Mesozoic Geology of Southwestern Arkansas*, Ann. Rept. Geol. Surv. of Arkansas, 1888; *The Comanche Series of the Arkansas-Texas Region*, Bull. Geol. Soc. Am., Vol. II, 1890; *Note on the Texas-New Mexican Region*, Idem., Vol. III, 1891.

Further accounts of the Cretaceous of Texas are to be found in the Second Ann. Rept. Geol. Surv. of Texas (Taff), and in the 18th Ann. Rept. U. S. Geol. Surv , Pt. II, pp. 217–237, Hill and Vaughan.

The *Trinity* series,[1] the oldest member of the system in Texas, is unconformable on the Triassic or older rocks. Its fossils are such as to have raised the question of its reference to the Jurassic system, but it is not commonly so classified. The basal part of the formation is like the Potomac of the east, in being non-marine, but the upper parts were deposited in sea-water. The series consists of sands, clays, marls, and limestones. In the lower part of the series any one of these various sorts of rock grades into any other, vertically or

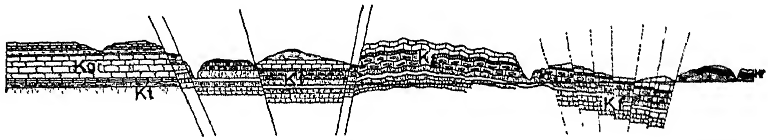


FIG. 381.—Section showing position of the Comanchean beds near Austin, Texas. The amount of faulting is exceptional. Length of section about 4 miles. (U. S. Geol. Surv.)

horizontally.[2] The series contains both asphalt and bitumen.[3] It extends northward to the Ouachita Mountains in Arkansas and Indian Territory, where the waters of the epoch appear to have had their shore. After the deposition of more than 2000 feet (maximum) of sediment, there appears to have been a shoaling of the waters, followed by a deepening which inaugurated the next epoch.

The *Fredericksburg* series, which overlies the Trinity, is more widespread than its predecessor, though it does not now cover all of the former, because of subsequent erosion. The series extends north to the Ouachita uplift, and perhaps around its western end over a limited area farther north, and west to New Mexico. The earliest beds of the series are clastic, and of shallow-water origin; but thick beds of limestone (or chalk) occur in other parts of the series. In the vicinity of the shores, especially next to the Ouachita uplift, where the shore phases of the formation are best known, the formation is relatively thin and mainly clastic. The Fredericksburg series is much less variable, both in thickness and composition, than the Trinity series below, and contains more calcareous material.

The Fredericksburg formation is overlain by the *Washita*, a series which records an epoch of shoaling waters, though the sea was some-

[1] Hill, op. cit., p. 129 et seq.
[2] Idem.
[3] Eldridge, Bull. 213 U. S. Geol. Surv., p. 301.

times clear enough to allow of the accumulation of impure limestone. The series is made up of alternating beds of clay, limestone, sandstone, etc.

In its typical development in Texas, more than half the Comanchean system is calcareous, and chalk, rather than limestone in its ordinary form, prevails. In general, the clastic beds thicken toward the Ouachita

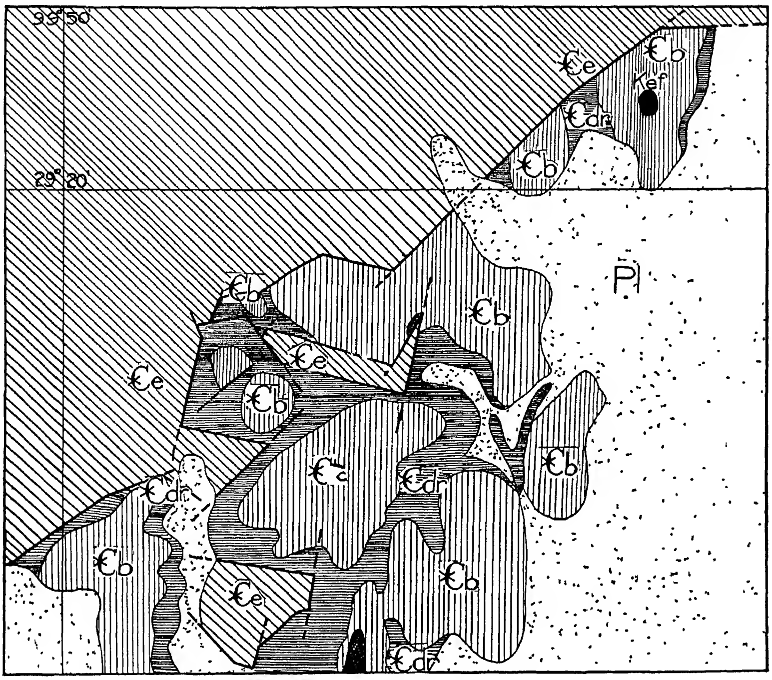


Fig. 382.—Shows the effects of faulting on outcrops of the various Cretaceous formations, near Uvalde, Texas. *Ce* (Edwards limestone), *Cdr* (Del Rio clay), and *Cb* (Buda limestone) are the local subdivisions of the Comanche system. *Kef* (Eagle Ford formation) is the lower part of the (Upper) Cretaceous.

Mountains, while the beds of chalk, which point to clearer water, thicken in the opposite direction. Locally the Comanchean system of Texas is deformed and notably faulted (Figs. 381 and 382).

Westward and northward extension. — The Comanchean formations originally spread westward from Texas over a considerable area in eastern New Mexico, and probably even to Arizona, where the system is 5000 feet thick[1] and carries the Texan fauna,[2] and north-

[1] Ransome, Professional Paper 21, and Bisbee folio U. S. Geol. Surv.

[2] Stanton, Professional Paper 21, U. S. Geol. Surv., p. 70.

ward around the western end of the Ouachita Mountains, an undetermined distance into Kansas.[1] Though they appear at the surface in small areas only, their extent may be considerable beneath younger formations. The exact relations of the Comanchean strata of Kansas (*Cheyenne* sandstone, *Kiowa* shale, etc.) to those of Texas have not been established. The Kansas beds appear to be referable mainly to the Washita epoch, though some of them may be older. The aggregate thickness of the Kansas beds is less than 200 feet. The Comanchean system also occurs in Oklahoma (near Garrett) and Colorado (near Canyon City).[2]

In Mexico.—As in Texas, the Comanchean system of Mexico is mainly limestone, and, though but imperfectly known, it has been estimated to have the extraordinary thickness of 10,000 to 20,000 feet. While the system in Mexico agrees with that of Texas in its large proportion of calcareous rock, the soft chalk of the plains grades into hard limestone in the mountains. This difference is perhaps the result of the dynamic movements to which the Mexican strata have been subject.

The distribution and character of the Comanchean system in Mexico are such as to show that a large part of that country was beneath the sea. It has been conjectured that the waters of the Atlantic and Pacific mingled over the site of some part of the present land, but this has not been proven. If there was union, it was probably across southern Mexico or perhaps even Central America, and so related, by shallow water restriction or by ocean currents, to the Californian coast, as to prevent free faunal intermigration.

In its abundance of limestone, the series of Texas and Mexico resemble the Lower Cretaceous of the northern part of South America, and southern Europe. It is a notable fact also, that the faunal affinities of the Comanchean system are with South America and Europe, rather than with California, where marine Lower Cretaceous strata are known.

[1] For summary of the Lower Cretaceous of Kansas, see Prosser, "Comanchean Series of Kansas," the Univ. Geol. Surv. of Kans., Vol. II, 1897. This volume gives bibliography of the Lower Cretaceous of the state. See also Hill, Am. Jour. Sci., Vol. I, 1895, and Bull. Geol. Soc. Am., III, p. 85; Gould, Am. Geol., Vol. XXV, pp 10–40; and Cragin, Am. Geol., Vol. VI, pp. 233–8.

[2] Stanton, Jour. Geol., Vol. XIII, p. 657.

The Northern Interior.

Though the sea is not known to have had access to the western interior of North America, north of Kansas, during the Comanchean period, clastic beds of fluvial or lacustrine origin, which should perhaps be referred to this period, are known at various points farther north. The beds in question (sometimes classed as fresh-water Jurassic under the names Morrison,[1] Como,[2] Atlantosaurus beds, etc.), occur in parts of Wyoming, South Dakota (Fig. 349), Colorado, and New Mexico,[3] though their distribution has not been accurately determined.[4] They probably reach northward to Montana, but they are best known along the Front range through Colorado and Wyoming,[5] and in the Black Hills.[6] They extend south beneath the marine Comanchean of southwestern Colorado, Oklahoma, and New Mexico.[7] Beds suspected of being of the same age are known in southwestern Wyoming and western Colorado. If these beds be the equivalent of the Morrison, the formation is distributed, perhaps with notable interruptions, over an area 600 miles long by 300 miles wide (Fig. 379). The limited exposures are due to the fact that most of the beds are covered by younger formations, being seen only where there has been deformation and erosion. The rather remarkable uniformity of thickness of the formation, as thus far reported (commonly between 200 feet and 300 feet), indicates that it was deposited on a

[1] Cross, Pikes Peak Folio, U. S. Geol. Surv., 1894.

[2] Scott, An Introduction to Geology, 1897.

[3] Lee, Jour. of Geol. Vol. X, pp. 36–50.

[4] The following references touch the question of the classification of these beds: Marsh, O. C., Proc. Amer. Assoc. Adv. Sci., 1878, Vol. XXVI, pp. 210, 220; Amer. Jour. Sci., ser 4, 1896, Vol. II, pp. 433–47; Amer. Jour. Sci., ser. 4, Vol. VI, 1898, pp. 105–15; Osborn, H. F., Jour. Acad. Nat. Sci. Phil., 1888, Vol. IX, p. 187, and Scott, W. B., Introduction to Geology, 1897, p. 477; Knight, W. C, Bull. Geol Soc. Amer., 1900, Vol. XI, pp. 383–87, and Wyo. Exp. Sta. Bull. 45, p. 138; Ward, Lester F., 20th Ann. Rept. U. S. G. S., 1900, Pt. II, p. 377; Williston, S. W., Amer. Jour. Sci., ser. 4, 1901, Vol. XI, p. 114, and Jour. of Geol., Vol. XIII, 1905, p. 338; Hatcher, J. B., 1903, Memoirs Carnegie Mus, Vol. II, No. I, pp. 67–72; Darton, N. H., Bull. Geol. Soc. Amer., 1904, Vol. XV, pp. 388, 425, and Edgemont and New Castle folios, U. S. Geol Surv.

[5] Knight classes the Como beds with the Jurassic. Bull. 45, Wyo. Exp. Station, p. 134.

[6] Ward, Jour. Geol., Vol II, p 250.

[7] Stanton, Jour. Geol., Vol XIII. The latest studies, reported in this paper, leave the age of this formation in doubt.

rather flat surface by agencies capable of distributing sediments with some degree of equality. These beds are frequently unconformable on older formations, including the marine Jurassic. In the Black Hills region, the Morrison beds are overlain by other non-marine beds of Early Cretaceous or Comanchean age,[1] some of which are coal-bearing.

Farther north, in Montana, Alberta, and Assiniboia, there is a series of beds (the Kootenay and Cascade formations, etc.)[2] similar in character to those just described, but not known to be connected with them. In the area where first described, the Kootenay formation occupies a narrow belt about 140 miles long and 40 miles wide. Similar beds have been discovered farther north. The Kootenay beds are mainly clastic, and are very inconstant in character, both vertically and horizontally. They contain some coal, and the fossils are mostly of plants of Early Cretaceous types.[3] The Kootenay formation is said to attain a maximum thickness of 7000 feet.

The non-marine Kootenay of these northerly localities rests unconformably on marine Lower Cretaceous beds, the fossils[4] of which are so like those of the Early Cretaceous of the Queen Charlotte Islands, as to lead to the belief that the beds in the two regions were contemporaneous and laterally continuous, and therefore that the sea of the northern interior entered from the west. The connection may have been in some such position as that of the late Jurassic (Fig. 348).

To the Morrison and Kootenay formations a lacustrine origin has usually been assigned. There is perhaps no adequate ground for questioning this conclusion for some parts of the formations, but the character of some of the beds and the nature and distribution of their fossils suggest a fluviatile origin for parts, and perhaps for large parts, of the series. The variations in the character of the beds within short distances is most easily explained as the work of meandering rivers.

[1] Darton and Smith, Edgemont, S. D.-Wyo. folio, and Darton, New Castle, Wyo.-S.D. folio, U. S. Geol. Surv.

[2] See Cascade formation, Fort Benton, Mont. folio, U. S. Geol. Surv.

[3] G. M. Dawson, Am. Jour. Sci., Vol. 38, pp. 120–127. A brief general description of the formation A fuller statement by the same author is found in Report Geol. Surv. of Canada, 1885. For the corresponding formations in the United States, see: Newberry, Am. Jour. Sci., Vol. XLI, pp. 191–201; Weed, Bull Geol. Soc. Am. Vol. III, 1892, pp. 301–23; Weed and Pirsson, 18th Ann. Rept. U. S. Geol. Surv. and Bull. 139, U. S. Geol. Surv.; and Wood, Am. Jour. Sci, Vol. 44, 1892, p. 401.

[4] Whiteaves, Contributions to Canadian Paleontology, Vol. I, Pt. II

It is not easy to see why fossils of plants and land animals should be so widely distributed, both vertically and horizontally, in a lacustrine formation, though their wide dissemination in a region of land deposits would be readily understood if the region were flat and subject to aggradation. The leg-bones of large land animals (dinosaurs) are frequently found upright, or inclined at some considerable angle to the bedding planes, as if the animals had been mired. Some of the bones of the Morrison beds are said to be in such condition as to show that they were exposed and partly decayed previous to their burial. In other cases, one end of a bone appears to have undergone subaërial decay, while the other was preserved. If one end was sunk in mud while the other was exposed, as might be in marsh or fluviatile deposits, this phenomenon would be explained. In the Black Hills region there are some beds of limestone composed largely of the secretions of fresh-water algæ.[1]

The position of these formations in reference to the Rocky Mountain axis is much the same as that of the Potomac to the Appalachian axis, and the same conception as to the mode of origin may be entertained. This involves some lacustrine[2] or quasi-lacustrine deposition, combined with fluvial and sheet wash aggradation. The extraordinary thickness assigned to some parts of the Kootenay formation (7000 feet) is scarcely credible under any hypothesis, except as interpreted on the principles of oblique deposition and subsequent thickening by shear and mashing.

It is not now possible to correlate the Kootenay formation with the Morrison, nor is it possible to correlate either the Kootenay or the Morrison with the Potomac, the Tuscaloosa, or the Comanchean of Texas; but, except perhaps the Kootenay, the other series are thought to correspond approximately with the Trinity of the Texas region, and with the lower part of the Potomac. The difficulty in the correlation of these formations with those of the coastal regions lies in the facts (1) that they nowhere approach each other, and so have no stratigraphic inter-relations, and (2) that there is no reliable standard with which they may be separately compared.

Between Kansas and the Black Hills of South Dakota, Lower Cre-

[1] Darton and Smith, Edgemont, S. D.-Neb. folio, U. S. Geol. Surv.

[2] Dawson, loc. cit.

taceous strata are not known. They may underlie some parts of the later formations between these localities, or they may be wholly absent.

The Pacific Border.

In the United States.—The Lower Cretaceous beds have great development in California, where they attain their maximum known thickness. They here constitute the *Shastan* group,[1] made up of two principal divisions, the *Knoxville* below, and the *Horsetown* above. The former has a maximum thickness of about 20,000 feet (according to estimate), and the latter of 6000 feet. These thicknesses are local and exceptional, but thicknesses of 12,000 to 15,000 feet have been calculated in several places. The Sacramento valley was the site of the thickest deposits, the sediments being furnished by the newly uplifted Sierra and Coast ranges. Throughout most of the great series, including the basal beds, there are evidences of shallow-water origin.[2] Dark clay slates predominate, but there is also a notable amount of sandstone. The fossils of the Knoxville beds, like those of the Jurassic of the same region, point to faunal connections with Russia, while those of the Horsetown beds seem rather to point to connections with southern Asia and Europe. These changes in life imply geographic changes of importance.

The Shastan group is found along the western side of the Sacramento valley, and in the Coast ranges of California, Oregon,[3] and Washington. Where its base has been observed, it sometimes rests on metamorphic rocks of unknown age, and sometimes on the Jurassic. It is overlain unconformably [4] in some places, and without apparent unconformity in others, by the Upper Cretaceous (Chico [5]), while in

[1] Gabb and Whitney, Paleontology of Cal., II; White, On the Mesozoic and Cenozoic Paleontology of California, Bull. 15, U. S. Geol. Surv.; Becker, Bull. 19, U. S. Geol. Surv.; Turner, Geology of Mount Diablo, Cal., Bull. Geol. Soc. Am., Vol. II; Diller, Cretaceous Rocks of Northern California, Am. Jour. Sci., Vol. XL, 1890, and Cretaceous and Early Tertiary of Northern California and Oregon, Bull. Geol. Soc. Am, Vol. IV, 1892; Diller and Stanton, idem, Vol. V, The Shasta-Chico Series, a Summary for the Pacific Coast brought up to 1894.

[2] Diller and Stanton, Bull. Geol. Soc. Am, Vol. V.

[3] Merriam, Jour of Geol., Vol. IX, 1901, p. 71.

[4] Becker, Bull. 19, U. S. Geol Surv., p. 12; also Monograph XIII, U. S. Geol. Surv, p. 188.

[5] Fairbanks, Jour. of Geol, Vol. III, pp. 415–430, and San Luis, Cal., folio, U. S. Geol. Surv.

still others, the latter system is absent.[1] The Knoxville formation of the Coast Range of California contains some igneous rock.[2]

The faunas of the Shastan and Comanchean systems are markedly unlike, and since the differences do not seem referable to climate, it seems necessary to suppose that there was some sort of a barrier between the two regions. In the United States, this barrier seems to have been a wide one, but in Mexico it was probably narrow, for the Comanchean fauna, or some part of it, extends west to the western part of Mexico (Sonora), while farther south the Pacific fauna reached eastern Mexico (San Luis Potosi). The exact position of the barrier which separated the oceans is not known. It appears to have lain farther west in northern Mexico, and farther east in southern. The failure of the two faunas to mingle does not prove the complete separation of the oceans, but it indicates that any connection there may have been was slight, or that the barrier between them extended well to the south, perhaps as far as Central America.

Though the exact time relations of the Comanchean and Shastan series have not been determined, they are believed to be approximately equivalent. It follows that the exact relations of the Shastan system to the Tuscaloosa and Potomac series are not defined.

North of the United States.—Farther north, the Lower Cretaceous beds (Queen Charlotte series) occur in the Queen Charlotte Islands,[3] where they have a thickness of between 9000 and 10,000 feet. In British Columbia, the coast line was east of the Coast Ranges, and extended farther and farther east with increasing latitude, until the ocean swept clean across the site of the Cordilleras in the early part of the period, and extended south along the area which is now the east base of the mountains.[4] In this southerly extension of the sea, the area of deposition was separated from the Pacific by land occupying the site of the Selkirks. The Kootenay formation is perhaps partly contemporaneous with these marine beds, but largely younger. The Comanchean system of British Columbia generally rests

[1] Roseburg, Ore., folio, U. S. Geol. Surv.

[2] Fairbanks, San Luis folio, U. S. Geol. Surv.

[3] Dawson, Geo. M., on the Earlier Cretaceous Rocks of the Northwestern Portion of the Dominion of Canada, Am. Jour. Sci., Vol. 38, 1889, pp. 120–127. This article contains a map showing relations of land and water on the northern Pacific coast in the early Cretaceous.

[4] Dawson, Science, March 15, 1901; and Bull. Geol. Soc. Am., Vol. XII, p. 87.

unconformably on the Triassic system, and contains some volcanic material and, locally, some coal.

Farther north, the Lower Cretaceous has not always been separated from the Upper, but the former has extensive development in some parts of northern Alaska,[1] where it locally contains coal, and is known even north of the Arctic circle. It is also believed to occur on the west coast of Greenland, opposite Disco island. From the fossils, the Greenland beds are believed to represent some such horizon as that of the Kootenay, or Potomac.[2]

Panama.—Conglomerate of Early Cretaceous age is said to occur on the isthmus of Panama,[3] its materials having been derived from the south. The Cretaceous beds here rest unconformably on formations of late Jurassic (probably) age.

The Close of the Comanchean (Lower Cretaceous) Period.

In the latter part of the Comanchean period, or at its close, there were considerable changes in the geography of the continent. Along the Atlantic and Gulf borders were changes (perhaps before the close of the period) which converted considerable tracts of the known Potomac and Tuscaloosa series from areas of deposition to areas of erosion. In Texas, the sea was withdrawn, and the Comanchean system was somewhat deformed and faulted, while in Mexico the deformation of the system was notable. Following these changes, the Comanchean system was subjected to prolonged erosion. Geographic changes also affected the western coast. Locally, as in the southern Coast range of California, there was folding of the Lower Cretaceous beds,[4] and volcanic activity, while in other places the sea spread itself over areas which had been land. Still other areas appear to have emerged at this time, and never to have been again submerged.[5]

On the whole, therefore, the deformative movements at the close of the Early Cretaceous period were considerable. They were more

[1] Schrader, Bull. Geol. Soc. Am , Vol. XIII, pp. 245–6, Professional Paper, 20, pp. 72–77; Mendenhall and Schrader, Professional Paper, 15, p. 37; and Collier, Bull. 218, U. S. Geol Surv., pp. 15–17.

[2] White and Schuchert, Cretaceous Series of the West Coast of Greenland, Bull. Geol Soc. Am., Vol. IX, pp. 343–368, 1898

[3] Hershey, Bull. Dept. Geol Univ. of California, Vol. 2, pp. 240–249.

[4] Fairbanks, Jour. Geol., Vol. III, pp 415–430, and San Luis folio, U. S. Geol. Surv.

[5] Ransome, Bisbee, Ariz. folio, U. S. Geol Surv.

extensive than those which occurred in the midst of any one of the Paleozoic periods as now defined, if the Mississippian and Pennsylvanian be regarded as separate periods. To appreciate the force of this point in its bearing on the distinctness of the Early and Later Cretaceous periods, it is needful to anticipate the history of the latter sufficiently to say that it was inaugurated by a notable submergence, affecting great areas. It brought the Atlantic and Gulf coastal plains beneath the sea, allowing (Upper) Cretaceous beds of marine origin to be deposited on the eroded surfaces of the Potomac, the Tuscaloosa, and the Comanchean series. In Texas, no species of marine life is known to have lived over the time-interval recorded by the unconformity between the two systems. Not only was the Texan area of the Comanchean series submerged, but the waters extended themselves far beyond their earlier limits, covering hundreds of thousands of square miles which had long been land. On the Pacific coast of the United States, the seas of the Late Cretaceous period extended farther east than during the Comanchean period in some places, for the Upper Cretaceous strata sometimes rest on pre-Cretaceous beds.[1] In British Columbia, the reverse was the case, while in some parts of Alaska, the Upper Cretaceous is unconformable on the Lower.[2] On stratigraphic grounds, therefore, the distinctness of the Lower Cretaceous from the Upper in North America is such as to warrant their recognition as separate systems, and their distinctness in some other continents is perhaps equally great. It is for these reasons that the Lower Cretaceous is here regarded as a system distinct from the Upper.

Thicknesses of strata afford no basis for the separation of systems, yet it may be noted that though the average thickness of the Comanchean system is not so great as the average thickness of the formations of most Paleozoic periods, yet its maximum known thickness (26,000 feet in California, measured by the customary method) is greater than that which any Paleozoic system is known to possess at any point in America.

The Lower Cretaceous in Other Continents.

Toward the close of the Jurassic period, it will be recalled, considerable areas of central Europe which had been submerged were

[1] Fairbanks, Am. Jour. Sci., XLV, 1893, p. 478.
[2] Schrader, Bull. Geol. Soc. Am., Vol. 13, Plate 40.

converted into dry land, while other areas emerged from the sea, but were not so situated as to be drained. In the deposits of some of the lakes, marshes, estuaries, and other lodgment basins which resulted from these geographic changes, the transition from the Jurassic period to the Early Cretaceous [1] is recorded. The oldest deposits in these non-marine waters in England (Purbeck beds) are classed as Jurassic, while later but conformable beds (Wealden) are generally regarded as Cretaceous. The interruption of marine sedimentation in southern Europe at the close of the Jurassic was less general, and over considerable areas the Lower Cretaceous succeeds the Jurassic conformably, both being marine. In Russia, the gradation from Jurassic to Lower Cretaceous is often so complete that no plane of division can be drawn between them.

The European areas of deposition may be grouped in two principal provinces, a northern and a southern. To the former belong the Cretaceous beds of England, central Europe, and Russia; to the latter, those of southern France, Spain, Italy, and the Balkan peninsula. The two provinces were separated by a series of islands which now form the highlands of France, southern Germany, and Austria. The northern province seems also to have been partly shut off from the Atlantic to the west. The southern province was continued east over the corresponding latitudes of Asia, and south over the northern border of Africa.

In Europe, as in North America, the Cretaceous, as that term has been used, is divisible into two major parts, a Lower and an Upper, as distinct as successive systems usually are. In general, the Lower is much more restricted in its distribution than the Upper, and is, to a larger extent, of non-marine origin. In both these respects, the Lower Cretaceous of Europe is in harmony with the Comanchean of North America.

During the initial stages of the Early Cretaceous period, the areas of sedimentation were more or less isolated; but later, advances of the sea enlarged some of these separated areas, and finally united many of them by bringing them beneath a common sea. The expansion of the epicontinental sea was still greater at the opening of the

[1] *Early Cretaceous* is here used instead of *Comanchean* for the time during which the strata corresponding to the Comanchean of the North American continent were laid down.

Later Cretaceous period. Stated in other terms, the widespread submergence of areas which were land during the Early Cretaceous period, marked the commencement of a new period, because it established new geographic relations of great importance. It should be stated, however, that the separation of the two systems in Europe, where the Upper Cretaceous is often conformable on the Lower, is some-

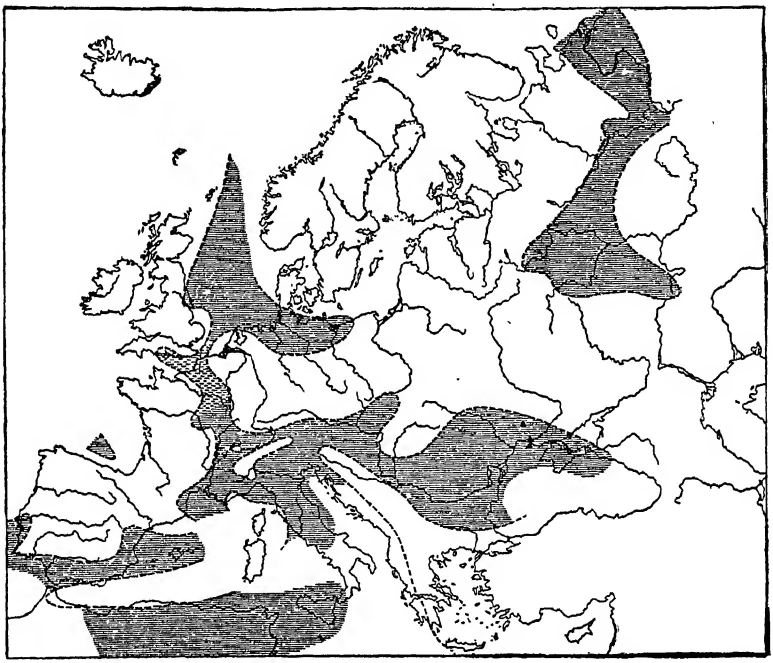


Fig. 383.—Sketch-map of Europe during the Neocomian stage of the Early Cretaceous period. The shaded areas are areas of deposition. (After De Lapparent.)

what less pronounced than in North America. The Upper Cretaceous is, however, much more widespread than the Lower.

The Cretaceous systems of England, France, and other parts of western Europe are best known, and the classification now somewhat generally accepted, though often with slight modifications, is based on the formations of that part of the continent, and is shown in the table on p. 109.

In other continents, the Lower and Upper Cretaceous have not always been clearly differentiated, yet enough is known to show that

the Lower and Upper Cretaceous systems are, in general, markedly different, both in origin and distribution.

In Europe.—The general relations of the Lower Cretaceous of western Europe have already been suggested. The lowest beds of the system in different regions are probably not strictly contemporaneous, for the basins in which they were deposited appear to have come into existence at somewhat different times, some of them enduring from the Jurassic period. The non-marine deposits of the early Neocomian were later succeeded, in many places, by beds of marine origin, and of greater extent.

The slow encroachment of the sea over western Europe during the Early Cretaceous period seems not to have been without interruptions, for reverse changes, more or less local and temporary, took place now and again, re-establishing lacustrine conditions, or severing marine communications between regions which had been overspread by a common sea.

In general there is great diversity in the formations of the Lower Cretaceous in central and western Europe. They embrace all sorts of clastic rocks, from coarse to extremely fine (plastic clays); also glauconitic beds, limestone, and beds of coal (northwestern Germany) and iron ore. They embrace, indeed, about all varieties of sedimentary rock except chalk, the rock from which the name "Cretaceous" was derived.

The iron ore which occurs locally in the Lower Cretaceous of Germany, differs from most formations of this ore. It occurs in beds made up of nodules of iron carbonate derived from the Jurassic beds. These ore beds are, therefore, of clastic origin. They reach a maximum thickness of nearly 100 feet. In general the Lower Cretaceous beds of Europe are more generally indurated than those of eastern North America.

In England, the Wealden formation is thought to have been accumulated as a great delta, 20,000 or 30,000 square miles in extent, in an inland body of water which occupied a part of England, and parts of the continent to the east. The sediments are thought to have come from the north. The later Neocomian beds of England contain some greensand (glauconite). The succeeding Gault series, mainly clastic and nearly 1000 feet (maximum) thick, is more widespread than the Neocomian.

In southern Europe the marine sedimentation of the preceding period was not interrupted, and the Lower Cretaceous beds rest conformably, and with poor definition, on the Jurassic. Limestone is here the most common sort of rock. In southeastern Europe, Lower Cretaceous beds are found in the southeastern part of Russia (Caucasus, Transcaucasia and Transcaspian regions) and about Moscow.

Other continents.—Lower Cretaceous formations of marine origin are widespread in Siberia, Japan,[1] and southern Asia, but in limited areas only in most other parts of tne continent. The system is believed to have slight development in the mountain regions of northwestern Africa, where it is really a continuation of the Lower Cretaceous of southern Europe, and is unconformable beneath the Upper Cretaceous, and in South Africa.[2] Marine Lower Cretaceous is also widespread in the northern part of South America, but not elsewhere east of the Andes. The absence of marine Lower Cretaceous beds east of the Andes in the southern part of South America is in keeping with its general absence about the borders of the South Atlantic generally. On the other hand, marine Lower Cretaceous beds occur in many places about the southern Pacific and Indian Oceans,[3] as in India, the Himalayan region, Australia, New Zealand, and at a few points on the east coast of Africa, and perhaps elsewhere. The areas where the system is exposed are, however, mostly small.

Climate.—In the aggregate, the known fossils of the Lower Cretaceous of America are not such as to indicate great diversity of climate. Even in Greenland, the climate seems to have not only been milder than now, but as warm as that of warm temperate regions of to-day.

While the climate of the Cretaceous periods has not been determined in detail, European fossils seem to afford better evidence of the existence of zones than those of America. From them paleontologists have thought to find warrant for the hypothesis that the climate underwent more or less fluctuation during the course of the periods.

The fresh-water fossils of those deposits of central Europe which represent the transition from the Jurassic to the Lower Cretaceous, are,

[1] Outlines of Geology of Japan, 1902, pp. 59–73.

[2] Ann. Rept. Geol. Com. Cape of Good Hope, 1901, p. 38: and Corstorphine, History of Stratigraphical Investigations in South Africa, Rept. S. Af. Assn. for Adv. of Sci., 1904. Geology of Cape Colony, Rogers, 1905, pp. 281–330.

[3] Neumayr. Erdegeschichte, Bd. II.

on the whole, of such a character, particularly as to size, as to indicate a climate which was far from tropical. So far as they afford a warrant for inference, the climate of central Europe would seem to have been comparable with that of the temperate portions of America to-day. The fossils of lower latitudes denote a warmer climate.

Close of the period.—Geographic changes of importance occurred in various parts of the earth at the close of the Early Cretaceous period, and are recorded (1) in the unconformities between the Lower and Upper Cretaceous systems, and (2) in the differences in their distribution. Unconformity between the two systems is recorded at some points in Europe, in North Africa, in Australia, where it is great, and in South America. The differences in distribution between the two systems will appear in the account of the following system.

THE LIFE OF THE COMANCHEAN PERIOD.

The terrestrial vegetation.—Fossil plants constitute the chief record of the life of the opening epoch of the Comanchean. The very earliest Comanchean flora was akin to that of the Jurassic, in that the cycadeans, conifers, ferns, and horsetails were the dominant forms. In Europe, where the Jurassic grades into the Cretaceous through the Purbeck and Wealden (and their continental equivalents), this rather monotonous group continued to hold possession of the land throughout the Lower Cretaceous, except in Portugal, where angiosperms appeared. The members of this group continued their slow modernization, but did not undergo any radical change in Europe during this period. So far as known, the same was true of Asia, Africa, and Australia, but data relative to these regions are scanty. The same appears also to have been true of northwestern America, where (in Shastan and Kootenay series) these groups made up the recorded flora and formed beds of coal.

The introduction of angiosperms.—But in the central and eastern American region representatives of the present reigning dynasty of plants, the angiosperms, including both monocotyledons[1] and dicotyledons, appeared in the Lower Potomac, and developed strongly during the period, so that by the opening of the (Upper) Cretaceous they seem

[1] Monocotyledons have been reported earlier, but the identification is not beyond question.

to have overrun all the continent. This is one of the most radical evolutions in the known history of the plant kingdom. While the precise time and place of origin of the angiosperms remains a question

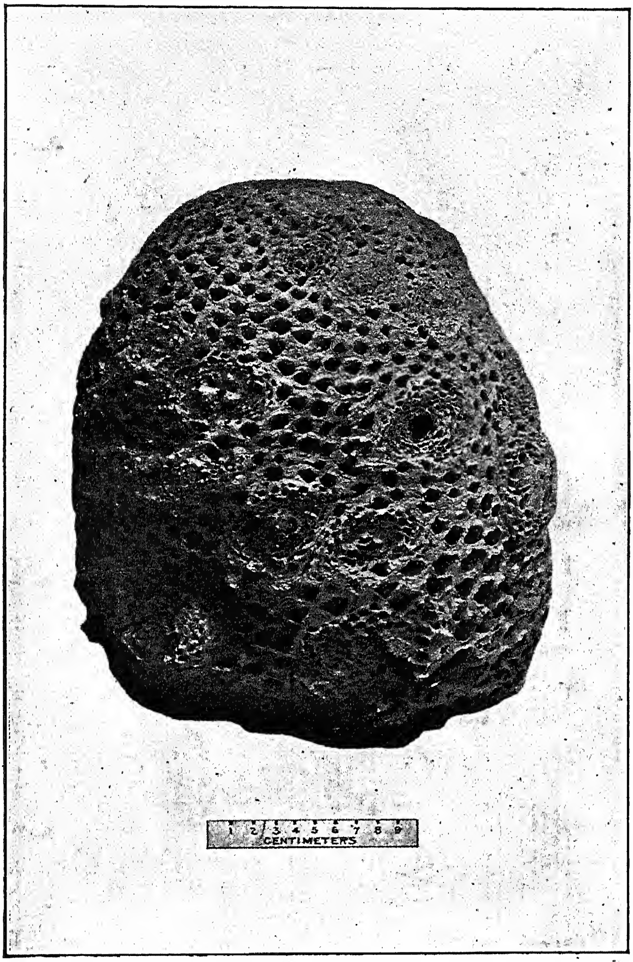


FIG. 384.—A cycadian trunk from the Black Hills, Dakota, *Cycadeoidea dakotensis* Ward, Lower Cretaceous. (After Ward.)

yet to be solved, present data seem to hedge it about more closely than most such questions. The evidence, as it now stands, points to the borders of the North Atlantic as the place of origin, and the late Jurassic or earliest Comanchean as perhaps the time, though the

evidence is less strong on this point. The new flora is best represented in the Potomac formation of the Atlantic coast, notably in Virginia and Maryland, where it has been carefully studied by Ward and Fontaine.[1] It is represented in the Tuscaloosa formations of Alabama[2] at a somewhat later stage (Upper Potomac), in Kansas in a higher (Washita) horizon,[3] and in the Black Hills.[4] The angiosperms do not occur in the lowest plant-bearing horizon of Texas, the Trinity, nor in the lowermost horizons in Kansas. The exact horizon of the angiosperms of the Black Hills, relative to that of the earliest angiosperms of the Atlantic coast, is not determined, but the angiosperms form a much smaller part of the flora, and its general aspect is less advanced. In west Greenland, about Lat. 70° N., the Kome series contains a few angiosperms, while in the next higher series, the Atane, probably Upper Cretaceous, the angiosperms outnumber the lower forms.[5] While exact correlation is impossible, it seems probable that the angiospermous evolution was there somewhat more tardy than on the Atlantic coast of the United States. In Portugal, primitive types of angiosperms appear in the Aptian stage (p. 109), but not among the 88 species of the Neocomian stage. At the top of the Lower Cretaceous, or base of the Upper (Albian stage), angiosperms are much more abundant, and belong to familiar genera (*Sassafras, Laurus, Eucalyptus, Myrica*). Interstratified with the several plant beds are fossiliferous marine beds which resemble those of the Comanchean series, but they do not afford the means of exact correlation, though they indicate that the Fredericksburg series approximately corresponds to the middle or upper portion of the Lower Cretaceous of Portugal, and favor the view that the Atlantic coast took precedence, both in time and numbers, in the evolution of the angiosperms. The limitation of the angiosperms to the mere border of the eastern continent is also more consistent

[1] Ward, Am. Jour. Sci., Vol. XXXVI, 1888, pp. 119–131; 15th Ann. Rept. U. S. Geol. Surv., 1896, Pt. I, pp. 463–542; Science, Vol. V, 1897, pp. 411–419.

Fontaine, Am. Jour. Sci., Vol. XVII, 1879, pp. 151–157, 229–239; Mon. XV, U. S. Geol. Surv., 1889 ; Proc. U. S. Nat. Mus., Vol. XV, 1892, pp. 487–495; Bull. 145, U. S. Geol. Surv., 1896.

[2] Smith, Rept. Geol., Coastal Plain, Ala., 1894, pp. 307–308.

[3] Knowlton, Am. Jour. Sci., Vol. L, 1895, pp. 212–214.

[4] Ward, Jour. Geol., Vol. II, 1894, pp. 250–266; 19th Ann. Rept. U. S. Geol. Surv., 1897–98, pp. 521–712.

[5] Heer, Flora Fossilis Arctica. White and Schuchert, Bull. Geol. Soc. Am., Vol IX, 1898.

with their introduction there by sea currents from the western continent, than with an origin on the eastern continent, for they were not there generally prevalent until the beginning of the Upper Cretaceous.

The view that seems best justified at the present stage of evidence is that the angiosperms developed on the old lands of the eastern part of North America, and that until the close of the Lower Cretaceous they had only spread westward as far as Kansas and the Black Hills, northward as far as Greenland, and eastward to the coast of Portugal, but not to Europe generally, nor to the western part of North America, for they do not appear in the Kootenay or the Shastan series. As the northeastern part of North America had long been land, and has left no record of plant-life, there is nothing to indicate how much earlier angiosperms may have begun their evolution there. The Jurassic beds of the western part of the continent and of Europe give negative evidence as to a dispersion earlier than the Cretaceous period.

In the most typical region on the Atlantic coast nearly half the known 800 species of Comanchean age are angiosperms. They began in marked minority in the lowest Potomac and increased to an overwhelming majority in the uppermost beds.[1] The earliest forms are ancestral, but not really primitive, and throw little light on the derivation of the angiosperms. While some are undifferentiated, the majority bear definite resemblances to modern genera, and some (as *Sassafras*, *Ficus*, *Myrica*, and *Aralia*), are referred to living genera, while others are given generic names implying the similarity of the fossil leaves to those of living plants (as *Saliciphyllum*, willow-like leaves, *Quercophyllum*, oak-like leaves, and analogous names for plants whose leaves resembled those of the elm, walnut, maple, eucalyptus, and others). To these were added, in the Amboy (N. J.) clays at the very close of the period, figs, magnolias, tulip trees, laurels, cinnamon, and other forms referred to modern genera, but not to modern species. The cycadeans had dropped to an insignificant place, and the conifers and ferns, while not equally reduced, were markedly subordinate to the angiosperms.

The land animals.—The aspect of the vertebrate life was intermediate between that of the Jurassic and of the Upper Cretaceous, and

[1] Newberry, Mon. XXVI, U. S. Geol Surv., 1895, p. 23.

has been sketched already. Very little is known of other forms of terrestrial life.

The fresh-water fauna.—The molluscan fauna of the inland waters had assumed a pronouncedly modern aspect as illustrated in Fig. 385. It had probably assumed considerable importance through the extension of the fresh waters, but the record is by no means so ample as would be expected if the deposits were made mainly in lakes and river channels, and this is an additional reason for the growing opinion that the terrestrial deposits were in considerable part the products of land-wash of the more transient type, due to overflows, storm-wash, sheet-wash, and other forms of more strictly subaërial aggradation.

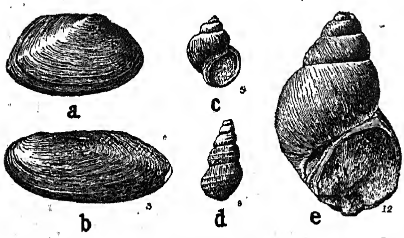


Fig. 385.—Fresh-water fauna of the Comanchean (Lower Cretaceous) from Montana (after Stanton). Pelecypoda: *a, Unio farri* Stanton; *b, Unio douglassi* Stanton; Gastropoda: *c, Viviparus montanensis* Stanton; *d, Goniobosis* (?) *ortmanni* Stanton; *e, Campeloma harlowtonensis* Stanton.

The marine faunas.—There were two very distinct series of marine faunas, implying two distinct maritime provinces—that of the Mexican Gulf and that of the Pacific. The former had its connections eastward with Portugal and the Mediterranean region, the latter, northward and westward with Asia and Russia. No species common to the two provinces is known. The two faunas were not only distinct, but were even contrasted in their generic aspects.[1] In the Gulf region, *Echinoidea* (Fig. 386, *a*-*c*), *Terebratulacea, Ostreidæ, Rudistæ, Chamadæ, Cyprina, Protocardia, Cyprimeria, Naticidæ, Glauconia, Turritella* (Fig. 386, *j*), *Nerinea, Hamites, Pachydiscus, Schlænbachia, Engonoceras*, and *Turrilites* are common, and some of them extremely abundant. But half of the above genera and families are absent from the Pacific province, the rest are rare or of local occurrence only, and always represented by different species. On the other hand, in the Pacific province, *Aucella* (Fig. 387, *k, l, m*), which is wholly absent from the Gulf region, is extremely abundant in the Knoxville beds, and *Belemnites, Rhynchonella* (Fig. 387, *r*), *Crioceras, Anchyloceras. Hoplites* (Fig. 387, *c*), *Phylloceras* (Fig. 387, *b*), and *Lytoceras* (Fig. 387, *a*), are common, while rare or absent from the Gulf province.

[1] Stanton, Jour. Geol., Vol. V, 1897, p. 607.

Trigonia (Fig. 386, *f*) is common in both, but the species are not related. It will be noticed that the pelecypods (Fig. 386, *d*-*h*), gastropods (Fig. 386, *i*-*l*), and echinoids dominate in the Mexico-Texan region, the oyster family being foremost, while the cephalopods (Fig. 387, *a*-*c*), and *Aucella* (Fig. 387, *k*, *l*, *m*), a pelecypod, dominate the Pacific fauna, though the list of gastropods (Fig. 387, *d*-*h*) and pelecypods (Fig. 387, *i*-*q*) is considerable there also. Corals and crinoids are rare in both provinces.

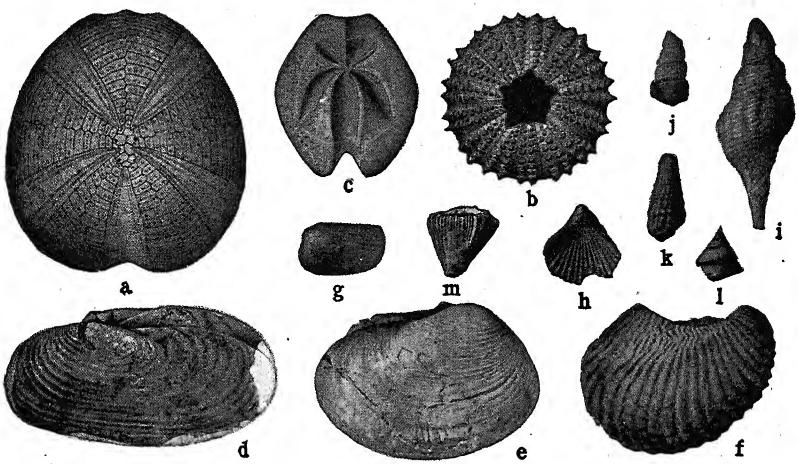


FIG. 386.—The Comanchean fauna of the Texan province. ECHINOIDS: *a*, *Holaster simplex* Shum.; *b*, *Diplopodia texanum* Roemer; *c*, *Hemiaster dalli* Clark. PELECYPODA: *d*, *Anatina austinensis* Vaughan; *e*, *Homomya austinensis* Vaughan; *f*, *Trigonia emoryi* Conrad; *g*, *Lima wacoensis* Roemer; *h*, *Pecten texanus* Roemer. GASTROPODA: *i*, *Fusus texanus* Vaughan; *j*, *Turritella budaensis* Vaughan; *k*, *Cerithium* (?) *texanum* Vaughan; *l*, *Trochus* Sp. CORAL: *m*, *Parasmilia texana* Vaughan. (After Vaughan.)

The question of the cause of this distinctness has already been alluded to, but cannot be positively answered. The complete distinctness and the contrast of aspect are obviously most completely explained by a land barrier separating the two provinces, much as at present, and there is now no proof that this was not the case. If, however, the oceans joined, the best appeal perhaps is to ocean currents of different temperatures. Assuming from general meteorological principles the existence of trade-winds, they would doubtless drive an equatorial Atlantic current westward through the opened tract and onward across the Pacific, while a northerly current might not improbably descend the Pacific coast, as one now does as far as British

Columbia, attended by a fauna quite different from that of the warmer coast farther south, not so affected. This is not an appeal to great climatic differentiation, which is not sustained by the flora, but to

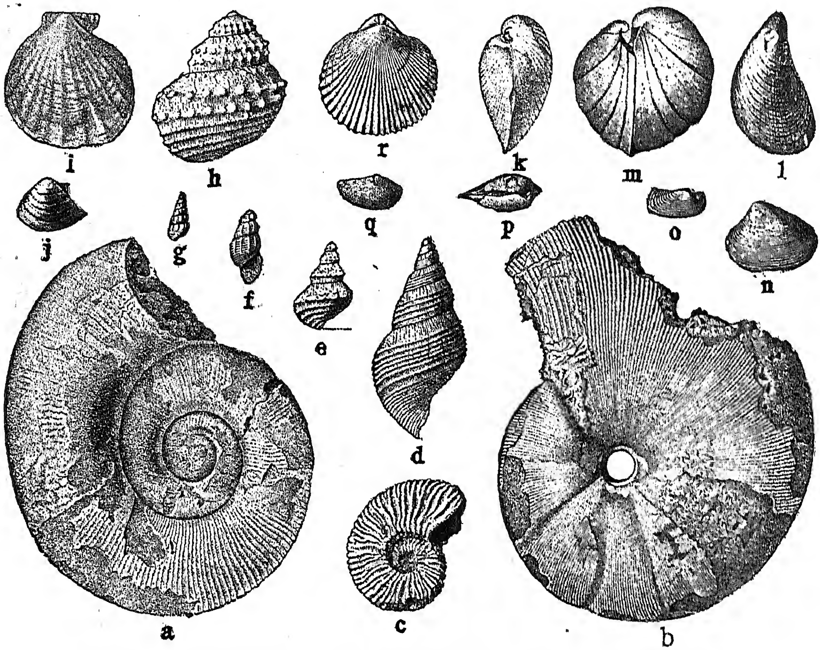


Fig. 387.—Fauna of the Shastan series, chiefly Knoxville. Cephalopoda: *a*, *Lytoceras batesii* Trask; *b*, *Phylloceras knoxvillensis* Stanton; *c*, *Hoplites angulatus* Stanton. Gastropoda: *d*, *Astresius liratus* Gabb; *e*, *Amberleya dilleri* Stanton; *f*, *Cerithium paskentaensis* Stanton; *g*, *Hypsipleura gregaria* Stanton; *h*, *Turbo moyonensis* Stanton. Pelecypoda: *i*, *Pecten complexicosta* Gabb; *j*, *Corbula* (?) *persulcata* Stanton; *k* and *l*, *Aucella piochii* var. *orata* Gabb; *m*, *A crassicollis* Keyserling; *n*, *Astarte californica* Stanton; *o*, *Arca tehamaensis* Stanton; *p*, *Nucula storrsi* Stanton; *q*, *Leda glabra* Stanton. Brachiopoda: *r*, *Rhynchonella whitneyi* Gabb. (After Stanton.)

such a moderate difference as has probably always existed between the high and low latitudes. The flora of the high latitudes is not tropical but warm temperate.

CHAPTER XV.

THE (LATER) CRETACEOUS PERIOD.

THE Later Cretaceous period (which will hereafter be called the Cretaceous) may be said to have been ushered in, so far as North America is concerned, by a notable encroachment of the sea on the land.

Within the land area of the North American continent, the Cretaceous occurs (1) along the Atlantic Coastal plain; (2) along the corresponding plain of the Gulf, both east and west of the Mississippi; (3) over the region of the Great plains, probably stretching north continuously from the Gulf of Mexico to the Arctic ocean; (4) at many points in the Cordilleran mountains, and (5) over considerable areas along the Pacific coast. In all these regions, the system is chiefly marine, though not without extensive fresh-water or terrestrial deposits. It thus appears that while the geographic distribution of the Cretaceous system has much in common with that of the Comanchean, the younger system is much more widespread (Fig. 388).

The Atlantic border region.[1]—The Cretaceous beds of the Atlantic coast come to the surface in a belt near the western margin of the Coastal Plain, immediately east of the outcrop of the Lower Cretaceous system. The principal exposures are in New Jersey, Delaware, Maryland, and Virginia. The lowest beds are not believed to represent the earliest beds of the system as developed elsewhere. The Cretaceous beds have been but little disturbed, and still dip, as when deposited, slightly to seaward. In that direction the beds pass beneath later formations.

The Cretaceous formations of the Coastal Plain are made up of conformable (probably) beds of clay, sand, limestone, and greensand

[1] Besides the State Reports referred to under the Comanchean, see Clark, Bull. Geol. Soc. of Am., Vol. 8, 1897, pp. 315–358, and Weller, Jour. of Geol., Vol. XIII, p. 71.

Fig. 388.—Map showing the distribution of the Cretaceous formation in North America. The conventions are the same as in preceding maps.

marl, the last being rather characteristic of the system. The beds of sand and clay are mainly unindurated, and do not differ notably from other sedimentary beds of similar materials. Of limestone, there is but little on the Atlantic coast, but more about the Gulf.

A chief constituent of the greensand marl is glauconite, primarily a hydrous silicate of potash and iron,[1] occurring in grains. Glauconite is now making in some parts of the sea, and from the positions in which it occurs, the following are inferred to be the conditions necessary for its origin:[2] (1) water of moderate depth, 100 to 200 fathoms being the most favorable; (2) a meagre supply of land-derived sediment, and (3) the presence of foraminifera. The production of the glauconite seems to be effected by chemical changes induced in the sediments as the result of the decomposition of the organic matter contained in the foraminiferal shells. The greensand marl of the Cretaceous system is somewhat widely distributed along the Atlantic coast, showing that the conditions for its origin were widespread. Since it is sometimes in distinct beds, separated from one another by formations of other composition, there must have been a recurrence of the conditions necessary for its origin; but even in those parts of the system where clay and sand predominate, glauconite is not generally altogether absent. Similar marls are found in the Cretaceous of Europe and in New Zealand, though in Europe they occur in the Lower system as well as the Upper. The abundance of greensand marl—not a common formation outside the Cretaceous—in the corresponding systems of different continents, adds another to the many striking inter-continental resemblances.

The Cretaceous formations of the Atlantic coast have certain peculiarities of structure, especially in that some of the beds when traced along the strike, wedge out in one direction or the other. The succession of thin beds of unlike constitution shows that the conditions of sedimentation were subject to numerous changes in the course of the period. These changes may have been the result of changing depths of water, changing heights of adjacent land, or of changing currents

[1] Glauconite is usually impure, and, as it occurs in nature, contains several other ingredients.

[2] For brief summaries concerning the origin of greensand marl, see Clark, Jour. of Geol., Vol. II, p. 161, and Reports of the State Geologist of New Jersey, 1892. For fuller accounts, see Challenger Report on Deep Sea Deposits.

in the water. The frequent variations in the character of a stratum when traced laterally show that different conditions prevailed at different points along the coast at the same time.

Thickness.—The aggregate thickness of the Upper Cretaceous beds nowhere exceeds a few hundred feet. In New Jersey it is about 500 feet, and in Maryland 200.

Classification.—Various classifications have been in use for the Cretaceous formations of the Atlantic coast, that now generally adopted being as follows:[1]

4. Manasquan formation.
3. Rancocas formation.
2. Monmouth formation.
1. Matawan formation.

These formations are not severally continuous throughout the Coastal region. Thus the Matawan formation does not appear at the surface south of Maryland, being overlapped in that direction by later beds. All the formations show notable variations when traced along their strikes, and borings to the east show that they also vary when traced to seaward from their landward margins.

Changes in the beds since deposition.—Though the beds have been but little changed since their deposition, the slight alterations are worthy of note. Locally, the porous beds of marl have been changed from green to brown by the decomposition of the silicate and the formation of ferric oxide. Cementation, chiefly by ferric oxide, has indurated certain beds at some localities, and many of the conspicuous hills within the area of Cretaceous outcrops owe their existence to a capping of this ironstone. The cemented layers are most likely to occur at the junction of formations of different texture, a generalization which holds in other unindurated, or but partially indurated systems. The limestone of the formation is often thoroughly indurated.

The Gulf border region east of the Mississippi.—Along the Gulf coast, as along the Atlantic, the Cretaceous beds appear at the surface some distance from the coast, and dip seaward at a low angle. The belt of their exposure extends from Georgia on the east, through Alabama

[1] Clark, Bull. Geol Soc. of Am., Vol. VIII, p. 326. See Repts. of the State Geologist of N. J. for older classification. The subdivision of this system, as proposd by Clark, has been somewhat modified by Knapp and Weller, Jour. of Geol., Vol. XIII, pp. 71–84.

and Mississippi to western Tennessee and Kentucky on the west and north. If any of the formations once had greater extension to the northward, as is probable, they have been removed by erosion.

The system is best known in Alabama[1] where three principal divisions are recognized; the *Eutaw* below (mainly clays and sands, some

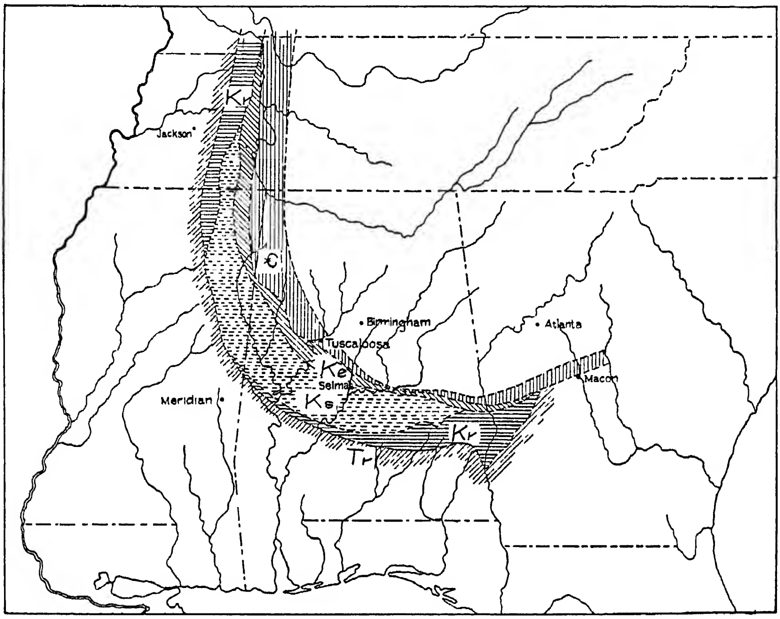


Fig. 389.—Map showing the positions of the several members of the Cretaceous system in Alabama and adjacent states. *C*, Tuscaloosa series; *Ke*, Eutaw formation; *Ks*, Selma chalk; *Kr*, Ripley formation; *Tr*, Tertiary. (After Smith.)

greensand, 300 feet), the *Selma Chalk* (*Rotten limestone,* 1000 feet) in the middle, and the *Ripley* (mainly sand, 200–500 feet) above. The Eutaw is believed to be the equivalent of the Matawan formation of the Atlantic coast, and the Ripley is thought to be older than the Rancocas. Either the area where the Cretaceous formations of the Gulf region are exposed emerged from the sea before the end of the period, or the youngest beds have been removed by erosion from the area where the system is exposed.

[1] For an account of the Cretaceous of Alabama, see Smith, Report of the Alabama Survey for 1894. See also Safford, Geology of Tennessee, 1869, and Hilgard, Geology of Mississippi, 1860.

The Cretaceous formations of Alabama illustrate some of the peculiarities of structure displayed by the corresponding beds of New Jersey. The Selma Chalk, which is thick in the western part of the state, thins to the eastward, and disappears altogether before the eastern border of the state is reached. Two formations in the eastern part of the state, therefore, seem to be the equivalent of the three in the western part. The interpretation of these relations has been suggested elsewhere. The relations of the several formations to each other and to the Tuscaloosa, are shown in Fig. 389.

The Cretaceous beds of the Gulf coast (Alabama) have been disturbed to a greater extent than the corresponding beds along those parts of the Atlantic coast where the system has been carefully studied. They have been deformed into low anticlines and synclines in some places, and even faulted (Fig. 390) to a slight extent.

FIG. 390.—Section of the Ripley formation on the right bank of the Tombigbee river, Alabama, above Moscow, showing deformation and faulting. The total thickness of the beds shown in the figure is not more than 75 feet. The faults are therefore slight. (Smith.)

The Western Gulf border region.[1]—The general stratigraphic relations of the system in this region are the same as farther east, but deposition seems to have been well under way before the oldest beds of the corresponding system farther east began to be laid down. The system here is much thicker than that farther east, and is made up of a series of alternating beds of sand, shale, limestone, and marl, most of which are of marine origin, attaining a maximum thickness of 4000 feet. Three principal series are recognized[2]: The Dakota (or Woodbine) formation; (2) the Colorado series, including the Eagle Ford, the Austin, and the Taylor formations, and (3) the Montana series, or Navarro formation.

The Dakota series, 600 feet and less thick, is largely of ferruginous, argillaceous sand, with some lignite, and is probably of non-marine origin. The Eagle Ford formation, about 500 feet thick, is essentially

[1] Hill and Vaughan, 18th Ann. Rept. U S. Geol. Surv., Pt. II, pp. 238–242.

[2] Hill, 21st Ann. Rept., U. S. Geol. Surv., Pt. VII, p. 114. These names supplant older ones. Woodbine is the equivalent of the old Lower Cross Timber, and the Taylor and Navarro formations were formerly described under the name Ponderosa.

of bituminous clay, with a little limestone. Its fossils are chiefly marine. The Austin formation, 600 feet or less thick, is limestone or chalk, of marine origin. The Taylor formation, 600 feet or so thick, consists of calcareous clay marls. The Navarro formation is similar to the last in constitution, but contains some glauconite. Its thickness is about 1000 feet. The Navarro formation is probably the equivalent of much of the Upper Cretaceous farther east. The succession of beds is in reality much more complex than the preceding statement would indicate, for some of the formations enumerated are made up of many beds of different composition. The oil of the Corsicana field of Texas is derived from the Montana series [1] (Webberville formation). Locally, the system is much faulted as shown in Fig. 382.

The Cretaceous system of Texas is continued north into Arkansas [2] where each of the above series is present. Together they have an estimated thickness of 1500 feet, though the original thickness was much greater. The system also extends west into New Mexico,[3] where it sometimes rests on the Red beds, and sometimes on Carboniferous limestone. Locally, as in the Cerillos hills, the system contains coal.

The Cretaceous of the western Gulf region differs from the corresponding system farther east, in its greater thickness, and in its greater proportion of calcareous matter, chiefly in the condition of chalk. Of limestone or chalk, the Cretaceous of the Atlantic coast contains little, that of the eastern Gulf region (Alabama and Mississippi) more, and that of Texas much. Nor is the chalk confined to Texas. The equivalent of the Austin formation (the Niobrara chalk) extends far to the north, and is the greatest chalk formation of the continent. Much of the chalk resembles the gray chalk of Europe, and some of it the white. Most of the American chalk, like the European, is made up in considerable part of foraminiferal shells. Fragments of coral and of molluscan shells, the spicules of sponges, and coccoliths, also abound.

Unlike the Comanchean system, the Cretaceous has not its greatest development in Mexico. While present in that country, it is less widespread and less thick than the preceding system.

[1] Hill and Vaughan, Austin, Tex., folio, U. S. Geol. Surv., p. 7.

[2] Hill, Ark. Geol. Surv., Ann. Rept, 1888, Vol. II.

[3] Johnson, School of Mines Quarterly, Vol. XXIV, p. 332, and Keyes, Am. Jour. Sci., Vol. XVIII, 4th series, p. 360.

The Western Interior.

Before the Cretaceous period was far advanced, non-marine sedimentation was in progress over an extensive area in the western interior. Later, the sea entered this region from the Gulf, covering a wide belt east of the Rocky mountains, and reaching perhaps to the Arctic ocean, thus connecting the subtropical seas with the polar.

The Cretaceous system of the western interior consists of the following subdivisions:

4. Laramie.
3. Montana.
    - Fox Hills.
    - Fort Pierre.
2. Colorado.
    - Niobrara.
    - Benton.
1. Dakota.

The Dakota formation.—The Dakota formation is mainly of non-marine origin, being comparable in this respect to the oldest formations of the Comanchean system, the Potomac, the Tuscaloosa, the lower part of the Trinity, the Morrison, and the Kootenay. (See note, p. 190.)

The Dakota formation is present over the Great plains generally, though buried over the greater part of the area. It extends westward beyond the eastern ranges of the western mountains, though in the mountain region, the area of deposition was greatly interrupted by elevations which rose above the lakes, marshes, or river flats where the sedimentation took place. In northern Montana, it is not known west of the Rocky Mountains.[1] The original eastern boundary of the formation is not known, for erosion has removed it from considerable areas which it once occupied. Remnants of the formation are now exposed as far east as eastern Iowa[2] and Minnesota. It must originally have covered an area 1000 miles wide and 2000 miles long within North America. Its outcrops are chiefly along the eastern and western borders of the plains, and in the mountains to the west. Here it sometimes overlaps Paleozoic and earlier Mesozoic formations, and rests on the Archean (Fig. 391).

[1] Willis, Bull. Geol. Soc. of Am., Vol 13, p. 326.

[2] Calvin, Iowa Geol. Surv., Vol. I, 1892; Bain, Idem, Vol. III, p. 108 and Vol. V, p. 267—a good review of the Dakota of Iowa.

North of the United States, it appears to be represented by conglomerate overlying the Kootenay series,[1] and beds correlated with it occur in the Frazer River valley farther west. 2000 feet of volcanic material, referred to this epoch, occurs in Crow's Nest pass.[2]

In the Plains region, the Dakota formation is largely sandstone (or quartzite) though it contains much conglomerate and clay, and some lignite. In general, it is coarser to the west and finer to the east, implying more vigorous drainage from the western side.

Along the east base of the Rocky mountains, where the beds have been tilted, the less resistant beds associated with the Dakota sand-

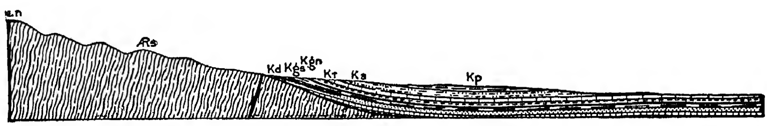


FIG. 391.—Section showing the Cretaceous resting on the Archean. Walsenburg, Colo., folio, U. S. Geol. Surv.

stone have been removed, leaving its outcropping edges as ridges or "hog-backs" (Fig. 392). These ridges are characteristic of the western margin of the Great plains, much of the way from New Mexico to Canada. Locally, the sandstone has a pronounced concretionary structure (Figs. 393 and 394).

The Dakota sandstone is often an important source of water in the semi-arid plains. It gets its water where it outcrops near the mountains, and the water flows eastward down the dip of the beds. In Dakota and elsewhere many of the deep wells go down to it for water for irrigation and other purposes.

West of the mountains of Colorado, the area of which was above water, the formation is less commonly sandstone. Clay or shale is here more abundant, and beds of coal of workable thickness give some clue to the physical conditions which prevailed, at least locally.

The Dakota formation has commonly been regarded as a lacustrine formation, deposited during an epoch of crustal oscillation during which the depth of the basin increased. The necessity for postulating numerous oscillations and nice adjustments is largely removed, if the formation be regarded as the joint product of subaërial and fluviatile depo-

[1] Dawson, Bull. Geol. Soc. Am, Vol. XII, p. 77.
[2] Ibid., p. 78.

sition, for deposits of this class furnish their own adjustments. The presence of bird tracks in the Dakota of Kansas [1] and the preservation of some 500 species of plant fossils, mostly the leaves of angiosperms, at various points and in conditions which forbid much transportation, imply the prevalence of subaërial conditions to a notable extent at least.

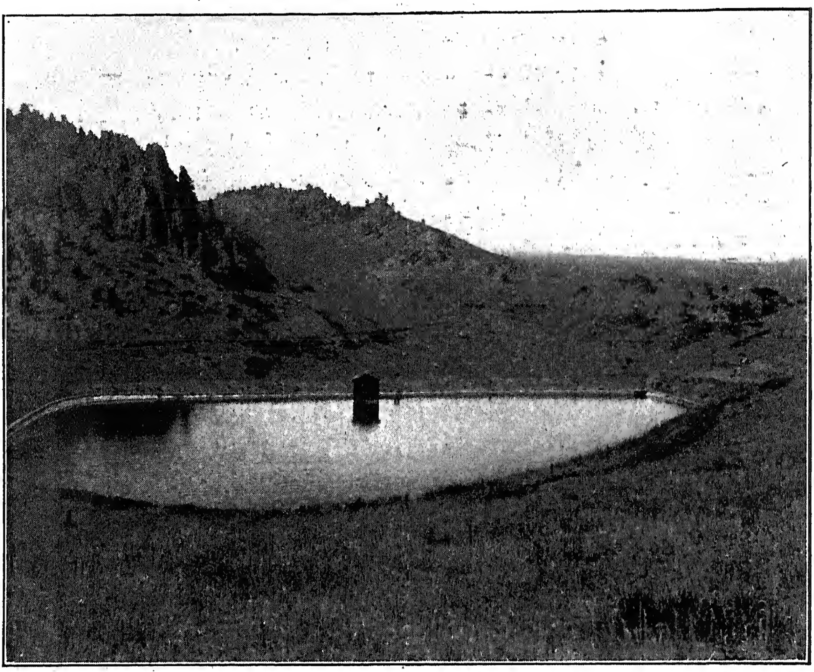


FIG. 392.—A Dakota "hog back." The rock at the left is the Red beds; the ridge near the center is occasioned by the outcrop of the resistant Dakota sandstone. Near Boulder, Colo. (Lees.)

The thickness of the formation is, on the whole, rather uniform, averaging perhaps 200 or 300 feet, though greater thicknesses are known.[2] To the south (Texas), the Dakota formation rests on the Comanchean system unconformably. Farther north it is often in apparent conformity with the Comanchean, though it often, as in the Wasatch and Uinta Mountains, rests on older formations.

[1] Williston, Univ. of Kans. Geol. Surv., Vol. IV, p. 50.

[2] Darton, 19th Ann. Rept. U. S. Geol. Surv., Pt. IV, and Knight, Bull. 45, Wyo. Experiment Station.

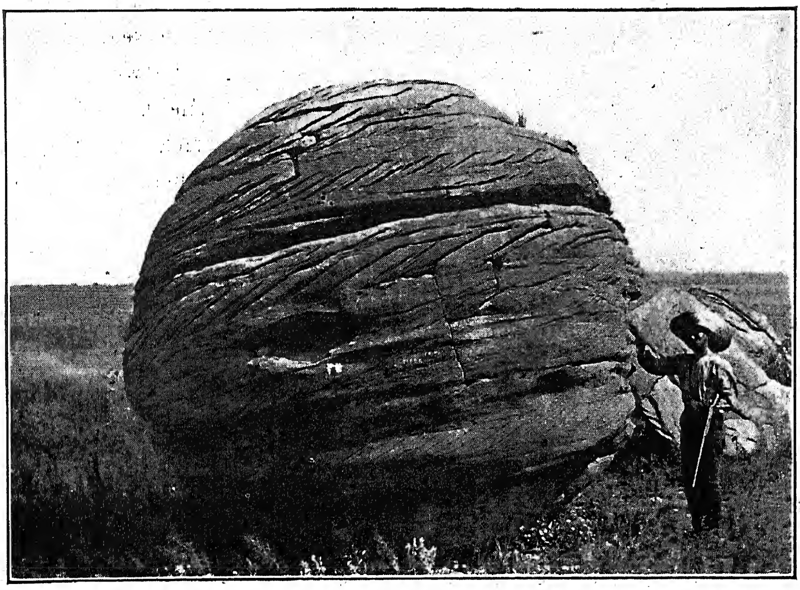


FIG. 393.—A concretion in the Dakota sandstone. Near Minneapolis, Kan. (Schaffner.)

FIG. 394.—A group of concretions weathered out from the Dakota sandstone. Near Minneapolis, Kan. (Schaffner.)

The Colorado series.[1]—The succeeding series records an extensive invasion of the North American continent by the sea. The submergence went so far as to establish a connection between the Gulf of Mexico on the south and the Arctic ocean on the north, over the site of the Great plains, thus dividing North America into two parts by a great mediterranean sea. It was probably not before this epoch, and perhaps not until the next, that the exposed Upper Cretaceous series of the Coastal plain began to be deposited, though exact correlation of these widely separated series has not yet been made.

The limits of the mediterranean sea of the Colorado epoch can only be approximately located. The western limit appears to have extended from northern Mexico, through Arizona, Utah, eastern Idaho, and western Montana into British Columbia, though at the west there were probably many islands, the cores of the present mountain ranges. The Black Hills, however, were probably submerged.[2] The eastern limit of the sea, so far as now known, lay in Minnesota, Iowa, and Kansas, east of the limit of the Dakota sandstone. In Minnesota and northern Iowa, outliers of the Colorado formation are found nearly to the Mississippi. To the south, the sea was constricted by the Ouachita uplift. The area of this uplift probably extended as a peninsula from Arkansas into Indian Territory and Oklahoma, and the sea passed around its western end. There may have been a connection between the Gulf and the mediterranean sea east of the Ouachita uplift, making the latter an island.

It is possible that the mediterranean sea of the Colorado epoch extended much farther east in the basin of the Upper Mississippi than is indicated above, for in a few places in Minnesota, Wisconsin, Iowa, Illinois, Missouri, and Indiana there are beds of gravel which represent the remnants of a once widespread formation, most of which has been destroyed. These remnants may be Cretaceous; but, on the other hand, they may equally well be much younger,[3] so far as now known. They are probably not marine.

Two principal divisions of the Colorado series are recognized, the *Benton* (chiefly shale) below, and the *Niobrara* (largely chalk

[1] For subdivisions of this series, see Logan, Jour. Geol., Vol. VII, pp. 83–91.

[2] Newton, Geology of the Black Hills.

[3] Salisbury, Jour. of Geol., Vol. III, pp. 655–667. See also Proc. Am. Assoc. for Adv. Sci., 1892.

and limestone) above. Both formations are of shallow-water origin. as shown by the structure of the beds at some points, by the bird tracks and remains of land animals at others, and by the species of shallow-water mollusks which abound throughout both formations. While clastic formations predominate in the Colorado series as a whole, there are also beds of chalk comparable to those of Europe, which gave the name Cretaceous to the corresponding system of the old world, Chalk occurs in Kansas,[1] Iowa,[2] Nebraska and South Dakota. The chalk is not only widespread, but its amount is very great, for it locally (mouth of the Niobrara) attains a thickness of 200 feet.

Beds of coal are of occasional occurrence in the Colorado series. They were probably formed about the borders of the sea, or about the islands which stood above it. Charred wood and even charcoal in the series point to the existence of forest fires during the epoch.

The aggregate thickness of the Colorado series is locally as much as 3000 feet, as strata are measured, though its average thickness on the plains is much less. It is between 400 and 500 feet in eastern Nebraska, and thickens westward.[3] It has a thickness of about 2000 feet on the west slope of the Black Hills.[4] Its distribution is shown in a general way on the map (Fig. 388).

At the close of the Colorado epoch there was some deformation of the beds of this and earlier series, as indicated by their relation to the beds of the following epoch.[5] These movements changed the relation of land and water somewhat, and the fossils of the succeeding series indicate that the sea was then deeper, at least locally.

The Origin of Chalk.

There has been much difference of opinion concerning the origin of chalk. Its resemblance to the foraminiferal ooze of the deep seas long since led to the belief that it was a deep-sea deposit; but closer examination has thrown doubt on this conclusion, for it appears that the points of difference between the chalk and foraminiferal ooze

[1] Williston, Univ. of Kans. Geol. Surv., Vol. II, and Logan, Jour of Geol., Vol. VII, p. 85.

[2] Calvin, Iowa Geol. Surv., Vol. III, pp. 213–235. A brief review of chalk in North America; good bibliography.

[3] 19th Ann. Rept. U. S. Geol. Surv.

[4] Darton, New Castle, Wyo.-S. D. folio, U. S. Geol. Surv.

[5] Emmons, the Denver Basin, Monograph XXVII, U. S. Geol. Surv.

are as striking as the points of likeness. Both consist chiefly of the shells of minute protozoans, largely foraminifera; but with them are associated shells of other types, some of which are similar in the two formations, and some dissimilar. The echinoderms, the sponge spicules, and the shells of certain microscopic plants found in the chalk seem to correspond in a general way with those of the oozes now depositing, and are consistent with the deep-water origin of the chalk. The molluscan shells of the chalk, on the other hand, seem to point with clearness to water no more than 30 to 50 fathoms deep. The distribution of the chalk and its relations to other sedimentary beds, seem to point to its deposition in water of moderate depth, rather than in water comparable in depth to that in which oozes are now formed.[1] That chalk may originate in shallow water seems to be clearly indicated by various facts which have been observed in connection with coral reefs, past and present.[2]

Another point of difference between chalk and foraminiferal ooze is found in their relative proportions of $CaCO_3$, the proportion being much higher in chalk than in ooze. The elevation and exposure of the chalk can hardly have led to this difference, for the extraction of the relatively soluble lime carbonate must have increased the percentage of the relatively insoluble impurities. On the other hand, the analyses of chalk which have been used in this comparison may have been from the purer portions of the formation, and since chalk grades off into chalky clay and chalky sandstone, varieties of chalk containing no more lime carbonate than the oozes, are doubtless to be found in abundance.

One of the peculiarities of the chalk beds is the presence in them of abundant nodules of flint and chert which are not present in the modern deposits resembling the chalk. These nodules seem to have resulted from the subsequent concentration into concretions of the siliceous material (sponge spicules, etc.), deposited along with the calcareous shells which make up the body of the chalk. On the whole, the balance of evidence seems to favor the hypothesis that the known chalk deposits were made in relatively shallow water. The conditions for the origin of the chalk seem to have been clear seas, with a genial

[1] Wallace, Island Life, pp. 89–96. The argument for the shallow water origin of chalk is here forcibly presented.

[2] Dana, U. S. Exploring Expedition.

climate. Foraminiferal shells may accumulate as well on the bottom of a shallow sea as on the bottom of a deep one. The purity of chalk depends not on the depth of the water, but on the absence of clastic sediments.

The Montana series.—Following the Colorado epoch, there were changes in the sedimentation and in the life of the western interior sea. The sediments of the Montana series are chiefly clastic, and the area of sedimentation was somewhat contracted. The beds are, for

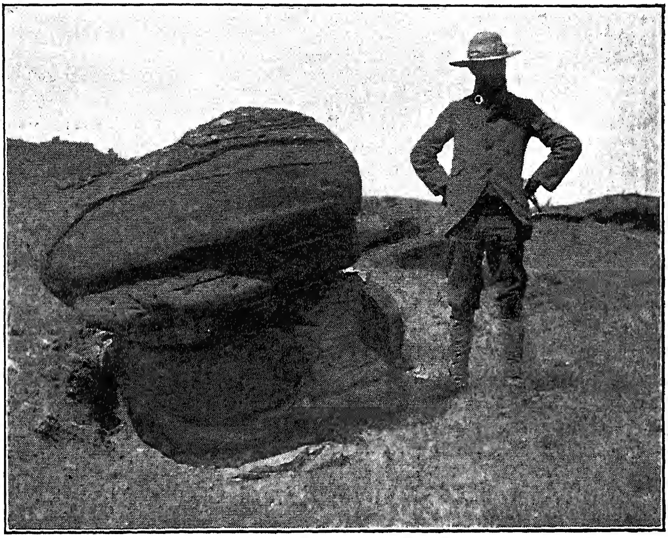


Fig. 395.—Fossil-bearing concretion in the Fox Hills sandstone, Carbon Co., Wyo. The concretions are of lime-iron-carbonate and contain many molluscan fossils.

the most part, marine, but the water shallowed as the epoch progressed, for the Ft. Pierre beds contain fossils referable to deeper water than those of the Fox Hills beds. Local beds of coal give evidence of local marshy conditions. Like other parts of the Cretaceous system of the west, the Montana series abounds in concretions, some of which attain great size (Fig. 395).

The thickness of the Montana series is variable, and its maximum is great. From 8700 feet (7700 being Pierre) in Colorado, it is reduced to 200 feet in some parts of the Black Hills, though it is much thicker in others.[1]

[1] Darton, New Castle, Wyo.-S. D. folio, U. S. Geol. Surv.

In the northern part of the United States (Montana) and in the territory beyond (Alberta), a large area of deposition appears to have come into existence at about the beginning of the Montana epoch. The deposits made in it constitute the *Belly River formation*, which is believed to be, at least in part, contemporaneous with the lower portion (Ft. Pierre) of the *Montana* series. Here also belong the *Judith River* beds.[1] Like other parts of the Cretaceous system, this formation contains some coal. The Pierre formation also yields oil at Boulder, Colo.

The Laramie.[2]—In the Laramie epoch, the submerged area of the western interior was still further contracted, and partially shut off from the ocean, and over a large area, in the Great plains and west of them, an area perhaps 2000 miles long and 500 miles wide, deposition was taking place in water which was sometimes salt, sometimes brackish, and sometimes fresh. Some of the deposits, too, were made in marshes and on low lands, rather than in water. In general, the area of deposition seems to have been near the critical level, and for a long time maintained a halting attitude, now above the sea and now below it. When below, it was so slightly below as not to bring about strictly marine conditions, and when above, it was so slightly above as to be in large measure undrained, or poorly drained. The Laramie series may be said to record the transition from the marine conditions of the Montana epoch, to the fresh water and land conditions of the Tertiary in the region concerned, just as the Coal Measures of the eastern interior represent the transition from the marine conditions of earlier times, to the terrestrial and lacustrine conditions of the Permian.

The general area of deposition is shown in Fig. 388. To the east the Laramie is concealed by younger beds, preventing the accurate determination of its border. To the north it reaches to the Lesser Slave lake, and perhaps beyond.[3] To the west, its border is often concealed by overlapping lava-flows.[4] To the south, its limit is uncer-

[1] Hatcher and Stanton, Science, Vol. XVIII, p. 212.

[2] For a full discussion of the Laramie, see White (C. A.) Bull. 82, U. S. Survey. A brief statement by the same author is found in the Proc. A. A. A. S., 1889, Vol. 38.

[3] McConnell, Geol. Surv. of Can. Am. Report, Vol. V, Pt. I. See also Dawson, Can. Geol. Surv. Rept. of Progress, 82–84, and Tyrrell, Ann. Rep. II for the Laramie north of the United States.

[4] Dutton, High Plateaus of Utah.

tain, because of imperfect exploration, and the presence of later beds which conceal or obscure it, and because of erosion which has removed it from considerable areas which it once covered. Of the Laramie in the Mackenzie valley little is known. Within the general area of the Laramie deposition, especially to the west, there were numerous islands, some large and some small, which furnished a part of the sediments. Neither the size nor the shape of these islands has been accurately determined.

Lithologically, the Laramie series consists primarily of sandstone and subordinately of shale; but with these clastic formations there is much coal. Both shale and coal are more abundant below than above, while in the upper part of the series conglomerate is not rare. In general, too, beds of non-marine origin increase in importance in the upper part of the series. The materials of the Laramie formation seem to have been derived principally from the pre-Paleozoic rocks of the mountains. This, as well as the fact that the Laramie beds participated in the deformation which the Paleozoic rocks have suffered, fixes the date of the principal deformative movements of the Rocky mountains as post-Laramie.

The thickness of the Laramie is estimated at 1000-5000 feet, exclusive of the transition (Mesozoic-Cenozoic) beds to be mentioned below. Some parts of the series, e.g., the coal, are such as to indicate slow accumulation.

Various points in the structure and surface relations of the Cretaceous of Colorado are illustrated by Figs. 396 to 398.

FIG. 396.—Section of Cretaceous in the plains of Colorado, showing the several formations dipping at a low angle toward the mountains and overlain in that direction by later Eocene formations. *Kd*, Dakota formation; *Kc*, Colorado formation; *Kp* (Pierre) and *Ktd* (Trinidad), Montana series; *Kl*, Laramie; *Epc* (Poison Canyon formation) and *Ech* (Cuchara formation) Eocene (?). Length of the section, about 15 miles. (Walsenburg, Colo., folio, U. S. Geol. Surv.)

In a considerable area in northeastern Wyoming, and in a large area farther north,[1] some of the Laramie lignite has been burned. The

[1] Allen, Proc. Boston Soc. Nat. Hist., Vol. XVI, p. 246, 1874; also Bastin, Jour. of Geol., Vol. XIII, p. 408. These phenomena were also noted and correctly interpreted by Lewis and Clarke. See report of their expedition.

burning was relatively recent, and locally is still in progress. The firing appears to have taken place on the sides of hills and valleys where the lignite outcrops. Back from the slopes where the outcrops occur, chimneys or vents appear to have sometimes developed, probably along joints, leading up from the burning coal to the surface, giving rise to "pseudo-volcanoes." The burning was accompanied by fusion, semi-

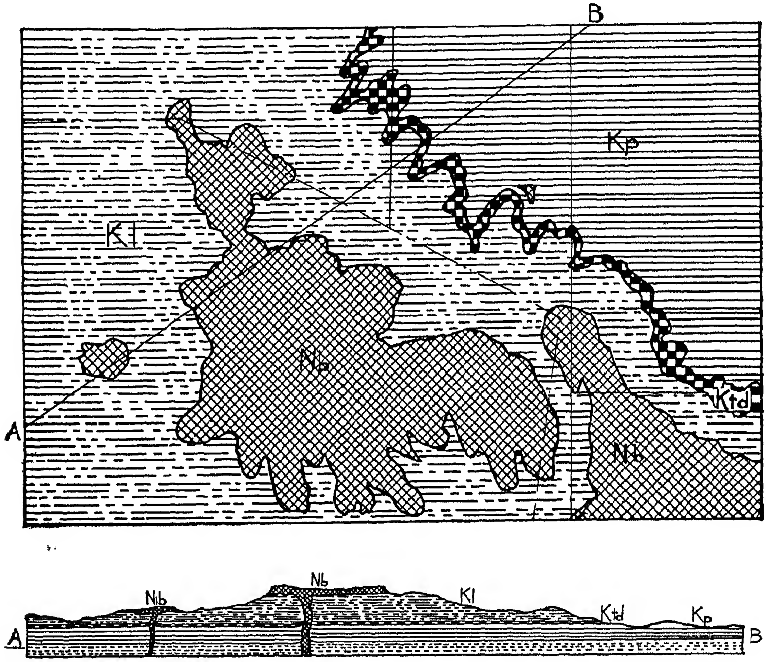


Fig. 397.—Map and section showing the position and relations of the several members of the Cretaceous system, and the effect of a lava cap in the prevention of erosion and in the development of mesas. *Kp* (Pierre formation) and *Ktd* (Trinidad formation), Montana series; *Kl*, Laramie series; *Nb* Neocene basalt. The section is along the line *AB* of the map. (Hills, Elmoro, Colo., folio, U. S. Geol. Surv.)

fusion, and baking, resulting in lava-like slag and brick-red banks of indurated clay. The former has had, and is still having a notable effect on the details of the topography developed by wind and water, while the latter gives striking color to the landscape. Incipient metamorphism accompanied the heat developed by the combustion.

Transition beds between Mesozoic and Cenozoic.—In general, the Laramie is conformable with the Montana below, as the preceding statements imply, and unconformable with the Eocene (Tertiary)

above. The break between the Laramie and Eocene is locally a great one,—has even been regarded as one of the greatest breaks recorded in the strata of the continent.[1] Locally, however, the association

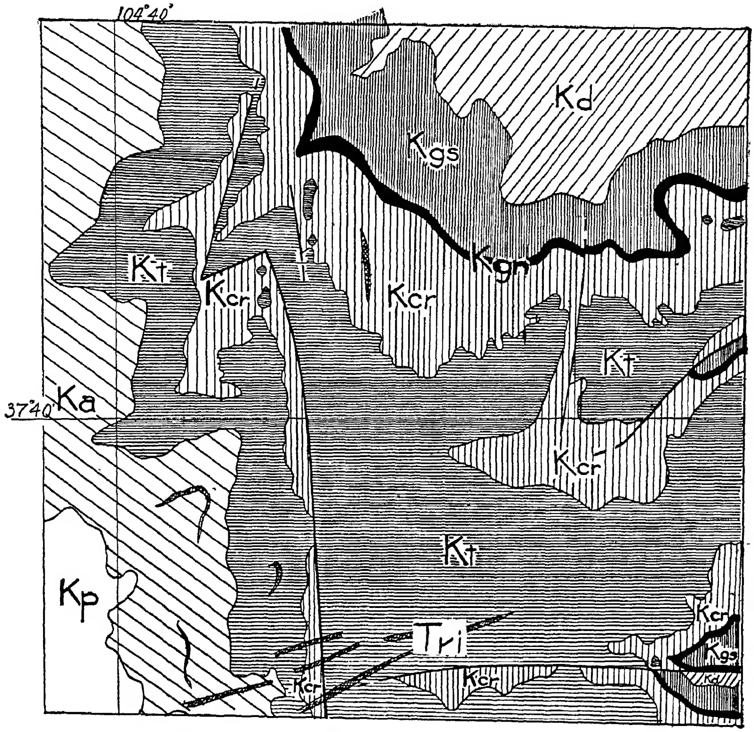


FIG. 398.—Map of a small area in Colorado, showing the outcrops of faulted Cretaceous formations. *Kd*, Dakota; *Kgs* (Graneros shale), *Kgn* (Greenhorn limestone), *Kcr* (Carlisle shale), *Kt* (Timpas shale), and *Ka* (Apishapa shale), Colorado series; *Kp* (Pierre shale), Montana series; *Tri*, igneous rocks of Tertiary age. (Hills, Walsenburg, Colo., folio, U. S. Geol. Surv.)

of the Laramie and Eocene is so intimate that agreement concerning the reference of certain beds, and even thick formations, has not been reached. Within what has often been called the Laramie series, there are local unconformities. Where these are slight, they probably have little significance in determining the classification of the beds. Slight unconformities are common in the Pennsylvanian system of the east, with which this series is most nearly allied in genesis. But

[1] Emmons, Orographic movements of the Rocky Mountains. Bull. G. S. A., Vol. I, p. 285.

there seems to be one unconformity which is neither slight nor local. The beds above and below it have sometimes been known as the Upper and Lower Laramie respectively. In Colorado the beds above the great unconformity have also been called post-Laramie,[1] and have sometimes been classed with the Cretaceous, and sometimes with the Tertiary. They include the Arapahoe (below) and Denver formations.

FIG. 399.—An outcropping ledge of clay, hardened by the burning of the coal-bed below. Except in the immediate vicinity of the burnt-out coal-bed, the clay is not indurated. Near Buffalo, Wyo. (Blackwelder.)

The Arapahoe formation is of fresh-water (or subaërial) origin, and 500 or 600 feet thick. The Denver formation, also of non-marine origin, has a maximum thickness of more than 1400 feet, the lower part being derived chiefly from andesitic lavas. The Ohio and Ruby formations in another part of Colorado[2] (2700 feet thick), and the Livingston formation of Montana,[3] as well as local formations elsewhere,[4] occupy the same stratigraphic position. The Livingston formation contains brackish-water fossils below and fresh-water forms above.[5]

[1] Geology of the Denver Basin of Colorado, Mono. XXVII, U. S. Geol. Surv.

[2] Anthracite and Crested Butte folio, U. S. Geol. Surv.

[3] Iddings and Weed, Livingston and Three Forks, Mont., folios, U. S. Geol. Surv.

[4] Cross, Am. Jour. Sci., 3d series, Vol. XLIV, 1892; pp. 19–42; also Mono. XXVII, p. 213 et seq., and Hills, Proc. Colo. Sci. Soc., Vol. III, 1891, p. 359–458.

[5] Cross, Mono. XXVII, U. S. Geol. Surv., p. 221.

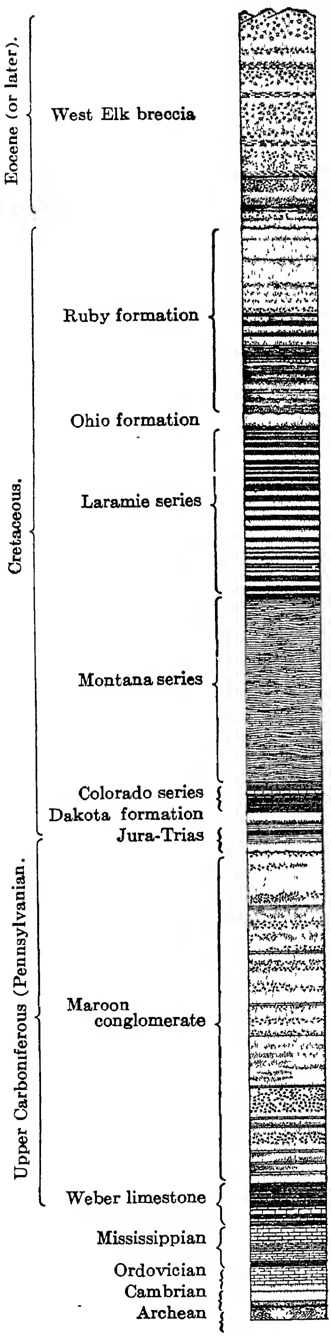


FIG. 400.—Section showing the formations in central Colorado. The Ohio and Ruby formations are represented in unconformity with each other, and with the Laramie and West Elk formations. (Anthracite-Crested Butte, Colo., folio, U. S. Geol. Surv.)

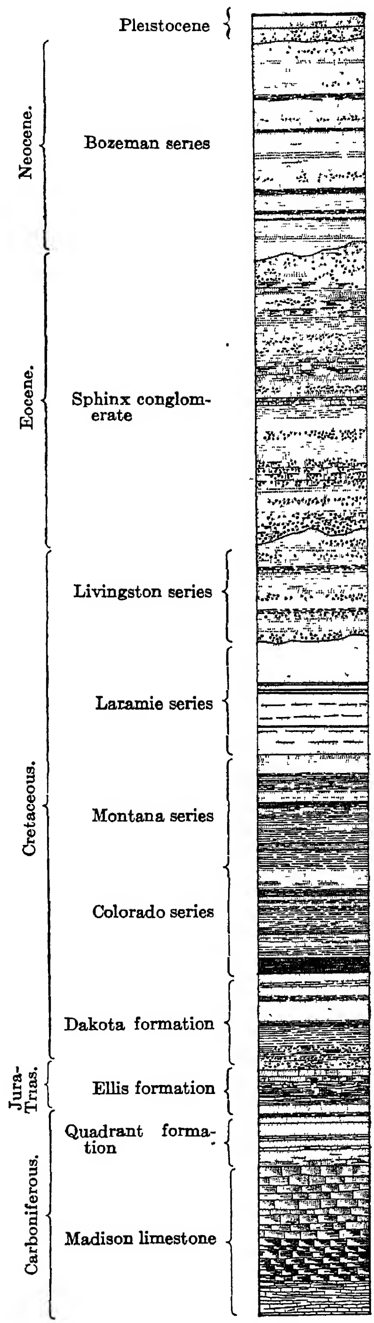


FIG. 401.—Section showing the Carboniferous and later formations of one locality in Montana. The figure is intended especially to show the stratigraphic position of the Livingston formation. (Peale, Three Forks, Mont., folio, U. S. Geol. Surv.)

In Colorado the amount of erosion between the epoch of the Laramie proper and that of the Arapahoe formation is thought to have been very great. Cross estimates it to have been 14,000 feet.[1] The time involved must, therefore, have been long. Between the Arapahoe and the Denver formations there is a lesser, though considerable unconformity, and the interval represented by it witnessed the occurrence of igneous eruptions on an extensive scale. It was from the lavas extruded at this time that the lower part of the Denver formation was derived.

Traced eastward, the Denver beds pass beneath Miocene beds. Stratigraphically, therefore, there is no reason why the Arapahoe and Denver formations should not be referred to the Eocene. The fossil plants of the Denver formation, of which something like 150 species have been identified, are consistent with this interpretation. But few species are common to the Denver and Laramie of Colorado, while an equal proportion are common to the Denver and the Eocene of other localities. The meager Arapahoe flora is more closely allied with the Denver flora above than with the Laramie flora below. The invertebrate fauna of the Denver beds is little known, and the identified species are common to both Laramie and Eocene. The vertebrate fauna has distinct Mesozoic affinities, and has been the chief reliance in classing the Arapahoe and Denver formations with the Laramie. If the presence of saurian fossils demonstrates the Cretaceous age of the beds containing them, the Arapahoe and Denver beds are Cretaceous; but every other consideration seems to point rather to their reference to the Early Tertiary.[2] After the deposition of the Laramie below, and before the deposition of the Arapahoe and Denver beds, there were great orographic changes, a long interval of erosion, and the initiation of the protracted period of vulcanism which marked the close of the Mesozoic. These physical changes were accompanied by marked changes in vegetation, and these changes had been accomplished before the deposition of the Denver beds. The great physical changes which inaugurated the changes in life appear to have taken place before the Arapahoe formation was deposited. Their effects had distinctly modified plant life by the time the Denver beds were deposited, but they appear to have had less effect on the vertebrate

[1] Op. cit., p. 217.

[2] This whole question is well discussed by Cross and others in the monograph cited.

life of the west, perhaps because conditions were not yet favorable for the incoming of the mammalian life from the regions where it originated.

The Livingston formation of Montana, consisting of brackish- and fresh-water sediments, with some intercalated volcanic agglomerates and breccias, rests unconformably on the (Lower) Laramie, and corresponds in its general relations with the Arapahoe and Denver formations. Its sediments were largely derived from the older sedimentary rocks which seem not to have contributed to the earlier Mesozoic formations, indicating post-Laramie-pre-Livingston deformation in this region. The Livingston flora resembles that of the Eocene, and the formation underlies fresh-water Eocene beds conformably. In some parts of Wyoming, on the other hand, beds thought to have been deposited at the same time as the Denver, Arapahoe, and Livingston formations are said to be a part of the inseparable Laramie series.[1]

The thickness of these formations, especially that of the Livingston, is very great, being estimated at 7000 feet.[2] Even if the sediments accumulated rapidly, as their nature indicates, this great thickness shows that the epoch was a long one.

Coal.—The Cretaceous is preëminently the coal period of the west. Coal-beds occur in every one of its principal divisions in this part of the continent. The total amount of coal, which is chiefly in the Laramie series, is comparable to that in the Pennsylvanian system, though the Cretaceous coal is not now so accessible, and its quality is inferior. It is estimated that along the east and west bases of the Rocky Mountains there are more than 100,000 square miles of coal-bearing lands, and Colorado alone is estimated to have 34,000,000,000 tons of available coal,[3] most of which is Cretaceous. The coal is largely lignite, though in Colorado not a little of it has been advanced to coking bituminous coal, and even to anthracite.[4] Anthracite referred to the Laramie also occurs farther south in localities where it has been affected by intrusions of igneous rock. The areas of Laramie coal are indicated in Fig. 241.

[1] Stanton and Knowlton, Stratigraphy and Paleontology of the Laramie and Related Formations in Wyoming. Bull. G. S. A., Vol. 8, pp. 127–156.

[2] Weed and Iddings, Livingston, Mont., folio, U. S. Geol. Surv.

[3] Storrs, 22d Ann. Rept. U. S. Geol Surv., Pt. III.

[4] See Anthracite-Crested Butte folio, U. S. Geol. Surv.

Thickness of the (Upper) Cretaceous system.—The maximum thicknesses of the Cretaceous series are something as follows: The Laramie (including the Livingston), about 12,000 feet; the Montana, 8700 feet; the Colorado, at least 3000 feet; the Dakota, about 300 feet. From these figures it will be seen that the Cretaceous system is comparable in thickness to the systems of other periods. It should be remembered, however, that these thicknesses represent maxima. In the Black Hills, the Cretaceous has in some places a thickness of no more than 1000 feet. In the Cinnabar Mountains (Montana), 4000 to 5000 feet; in the vicinity of Denver, about 13,000 feet; in Utah, about 10,000 feet; in Kansas, 1000 to 1300 feet; in New Mexico, 3500 feet; in Manitoba, where the strata rest on the Devonian, 2000 feet, and along the Northern Rockies in Canada, about 10,000 feet.[1] But even these figures are much greater than those for most of the systems of the Paleozoic periods, over the larger part of the area where they occur.

The Pacific coast.[2]—On the Pacific coast, the Cretaceous system is represented by the marine beds which constitute the *Chico* series, which, at the time of its origin, probably extended along the coast from Lower California to the Queen Charlotte Islands. The series is found largely in great structural valleys, which were formed in pre-Cretaceous times.[3] That part of the system which has escaped erosion has a thickness of 4000 feet in some parts of California. The Chico series rests on the Shastan or Comanchean unconformably in the southern part of the Coast Range of California,[4] and overlaps the Shastan system at other points, resting on the Jurassic in the Sierras, and on Paleozoic formations in southern California.[5] In some places the Chico series rests on the Knoxville formation, the Horsetown formation being absent.[6] Farther north, the Chico series sometimes rests on the Shastan (Comanchean) system with apparent conformity, thus affording a local exception to the relation which generally subsists between the two systems. In some parts of the Klamath Mountains, it rests on schists of Devonian or greater age. In some parts of Oregon, the

[1] Am. Rept. Geol. Surv. Can., Vol. I. (N. S.), p. 69 B.

[2] See papers of Diller, Stanton, and Turner, cited under the Lower Cretaceous (Shastan), p. 122.

[3] Anderson, Proc. Cal. Acad. Sci., Third Series, Vol. II, Pt. I.

[4] Fairbanks, Jour. of Geol, Vol III, p. 426.

[5] Fairbanks, Am. Jour. of Sci., Vol. XLV, 1893, p. 478.

[6] Anderson, op. cit.

Chico is wanting where the Lower Cretaceous is present.[1] In British Columbia, the Shastan period seems to have been inaugurated by subsidence, but as the period progressed the area of land increased till the sea failed to cover the Cordilleran belt.[2] Formations younger than the Dakota are not known in British Columbia between the Coast range and the Selkirks,[3] but along the coast there are formations correlated with the Colorado and Montana. Upper Cretaceous formations are also known in western Alaska.[4] In Vancouver Island, the Chico is reported to be coal-bearing.

The relations between the Chico beds and the Cretaceous formations of the interior have not been determined but the remaining portions

Fig. 402.—Section showing the position of the Cretaceous beds in western Oregon. *Mg*, meta-gabbro of unknown age; *sp*, serpentine; *as*, amphibolite schist; *Jr*, Jurassic (?); *Km* (Myrtle formation), Cretaceous, and *Kmw*, lentils of limestone in the Myrtle formation; *Eu* (Umpqua formation), Eocene; *Ed*, Eocene diabase. (Diller, Roseburg, Ore., folio, U. S. Geol. Surv.)

of the former do not appear to represent the latest part of the system. The region may have emerged before the closing stages of the period, or the beds then deposited may have been removed by erosion.

Climate.—The climate of North America during the Cretaceous period seems to have been uniform and warm throughout a great range of latitude. In Greenland, Alaska, and Spitzbergen, the climatic conditions seem to have been similar to those in Virginia. Toward the close of the period, however, the climate seems to have been cooler, for the Laramie flora is a temperate, rather than a tropical one.

Close of the Period.

The Cretaceous period is commonly said to have been brought to a close by a series of disturbances on a scale which had not been equaled since the close of the Paleozoic era, and perhaps not since the close of the Algonkian. These changes furnish the basis for the classification which makes the close of the Cretaceous not the close of a

[1] Roseburg, Ore., folio, U. S. Geol. Surv.

[2] Dawson, loc. cit.

[3] Dawson, Bull. Geol. Soc. Am., Vol. XII, p. 77.

[4] Schrader, Bull. Geol. Soc. of Am., Vol. XIII, p. 247.

period merely, but the close of an era as well. While these changes are commonly said to have taken place at the close of the Cretaceous, it is probably more accurate to say that they began late in the Upper Cretaceous, and continued into the succeeding period. The close of the Cretaceous may be said to have been the time when these changes first made themselves felt profoundly. They consisted of deformative movements, a part of which were orogenic, and of igneous eruptions on an unprecedented scale.

General movements.—In the closing stages of the period, the sea which had lapped over the Coastal plain of the Atlantic and Gulf was withdrawn toward the abysmal basin. Data now in hand point to the emergence of the eastern Gulf region in advance of the Atlantic coast, while the emergence of the Texan area was probably still later, and this implies that the changes were not due wholly to variations of the sea, but in part at least to differential warpings of the coastal belt. The Appalachian mountains, which had their first period of folding during the Permian, and which had been reduced to a peneplain by the beginning of the Cretaceous, were bowed upward at some later time, and this second period of growth seems to fall within the general period of deformation here under consideration. This later movement was chiefly vertical, while the Permian deformation was primarily horizontal.

In the western interior, the prolonged period of crustal oscillation which marked the Laramie, marked also the beginning of the end of the Cretaceous. By the close of the Laramie, the sea had withdrawn from the extensive area occupied by the Great plains, and from large areas in the mountains west of the plains. It is probable, indeed, that most of the Cordilleran region was elevated bodily at this time, though not to its present height. Great areas which had been submerged were however brought above the critical level, and the movements were, therefore, recorded. Records of similar movement in some other regions where they probably took place are wanting, or the record is less clear; but it is probable that the eastern interior underwent changes of level, relative to the sea, at this time. Enough is known to make it clear that a large part of the continent was affected by the general withdrawal of the sea.

Orogenic movements.—The development of mountains by folding was probably in progress in the last stages of the Cretaceous period,

from Alaska on the north, to Cape Horn on the south, more than a quarter of the circumference of the earth. Similar movements probably affected the Antillean mountain system,[1] lying between the southern end of the Cordilleran and the northern end of the Andean systems, for in several of the Antillean islands, later formations rest unconformably on the deformed Cretaceous beds. Locally, as where the Eocene rests conformably on the Laramie, the disturbances of this time are not clearly distinguishable from those of later date, which increased the deformation initiated at this time. Some of the folded ranges of the Cordilleran system began their history at this time; others had a new period of growth, and still others date from a later period. Yet the close of the Laramie was, *par excellence,* the period of orogenic movement in the western part of North America. The Rocky Mountain system may be said to have had its birth at this time. That the existing mountains are not older is shown by the deformation of the Laramie beds along with those of greater age. That this folding was not younger is shown by the lack or slightness of deformation of the Tertiary beds in the same region.

North of the United States, the site of the Laramide range (the continuation of the Rockies of the United States) had been a tract of great deposition through Paleozoic and Mesozoic times. In it, sedimentary beds had accumulated to a thickness, which, by the usual methods employed in such cases, is estimated at 50,000 feet.[2] At this time the strata, doubtless already inclined and bowed as incidents of deposition, were tilted, folded, and faulted into the Laramide range. The thrust producing the folding and faulting appears to have come from the west, as implied by the position of the overthrusts. The height of the mountains developed in this region at this time is estimated at 20,000 feet. The mountains have since undergone further elevation, and had erosion not reduced them, it is estimated that their present height would be 32,000 to 35,000 feet. It has been calculated that in the Laramide range a surface belt 50 miles wide was reduced to one half that width.[3] Estimating the average height of the faulted tract at about half the maximum height,

[1] Hill, Nat. Geog. Mag., Vol. VII, p. 175.

[2] Dawson, Science, Vol. XIII, 1901, p. 401, and Bull. Geol. Soc. Am., Vol. XII, p. 88.

[3] Dawson, Bull. Geol. Soc. Am., Vol. XII, p. 87.

the thickness of the crust involved in the deformation would be about three and a half miles.

Within the United States, comparable, if less extensive, elevations, deformations, and faultings took place along the southward continuation of the Laramide range. At every point where the Rockies have been studied, the post-Laramie deformation has been found to overshadow both earlier and later deformations. Dana has called the whole chain of mountains which received its initiation at this time, the Laramide system.[1]

West of the Rockies, there were also orogenic movements along more or less parallel tracts. Many of the ranges of the west have not been studied in detail, but most of those whose history has been worked out show deformation at this time. Here may be mentioned many of the mountains of Colorado[2] and Wyoming, and the Wasatch and Uinta Mountains of Utah. In northern California and southern Oregon there were deformations, as shown by the unconformity between the Upper Cretaceous and the Eocene, but the deformation here seems to have been less intensive than farther east. Locally, however, it is thought to have been sufficiently violent to develop the anomalous sandstone dikes of northern California (Fig. 417, Vol. I)[3]. In British Columbia west of the Gold range, there had been a broad tract of deposition 250 miles in width. The beds (largely igneous) which had accumulated in this syncline, estimated, in the usual way, to be 40,000 feet (maximum) in thickness, suffered deformation at this time. Metamorphism here was so intense as to make the separation of Archean and later rocks impracticable.[4] As in the Laramide range, the relief produced was great. In intensity of tangential thrust, the disturbances of this time were in contrast with those of other periods throughout most of the area between the Sierras on the west and the Great plains on the east.

Faulting.—The mountain formation at the close of the Cretaceous period was accompanied by faulting on a somewhat extensive scale throughout the region of movement, though the faulting of this

[1] Dana, Manual of Geology, 4th ed.

[2] See folios of the U. S. Geol. Surv. for Colorado, Wyoming, and Montana. Also Emmons, Bull. Geol. Soc. of Am., Vol. I.

[3] Diller, Bull. Geol. Soc. Am., Vol. I, p. 411; and Downieville, Cal., folio, U. S. Geol. Surv.

[4] Dawson, loc. cit.

time cannot always be distinguished from faulting of later date. In the Rocky mountains of British Columbia, one overthrust fault

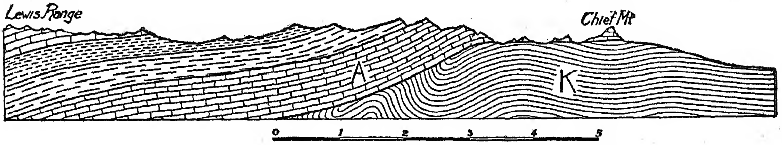


FIG. 403.—Section in northern Montana, showing Proterozoic rock, *A*, thrust over Cretaceous, *K*. Subsequent erosion has removed much of the overthrust beds, but Chief Mountain is a remnant of them. The extent of the overthrust is unknown.

has been located which crowded the Cambrian rocks obliquely up over the Cretaceous. The horizontal displacement is estimated to

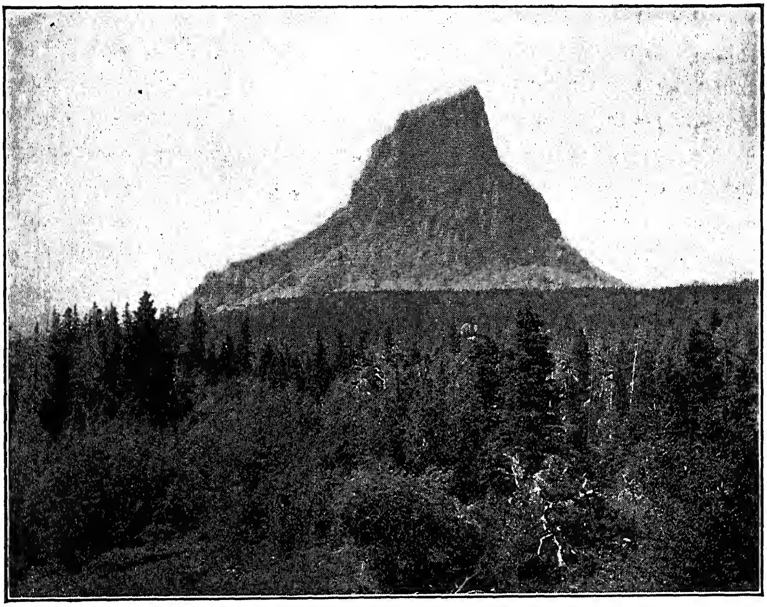


FIG. 404.—Chief Mountain. (Willis, U. S. Geol. Surv.)

be as much as seven miles,[1] while the throw is as much as 15,000 feet. Near the national boundary, the displacement of what appears to be the same fault crowded the Proterozoic up over the Cretaceous[2] by a movement of equal magnitude (Fig. 403). The exact date of

[1] McConnell, Geol. Surv. of Canada, Vol. II, Rept. D, p. 33, 1886.
[2] Willis, Bull. Geol. Soc. of Am., Vol. 13, pp. 307, 331–5.

these faults has not been determined, but they occurred during the general period of disturbance inaugurated at the close of the Upper Cretaceous. The position of the Cretaceous near Livingston, Mont., is shown in Fig. 405, while the effect of faulting on outcrops in the plains of Colorado is shown in Fig. 398.

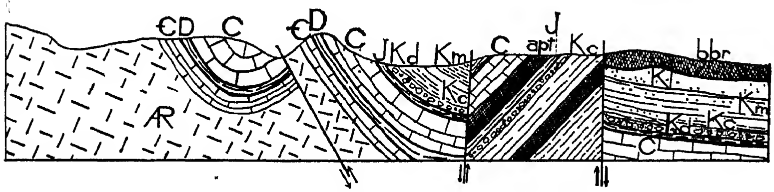


FIG. 405.—Section showing position of Cretaceous beds at one point in the vicinity of Livingston, Montana. Æ = Archean; Є, Cambrian (Gallatin and Flathead formations); *D*, Devonian (Jefferson formation); *C*, Carboniferous (Quadrant and Madison formations); *J*, Jurassic (Ellis formation); *Kd*, Dakota formation; *Kc*, Colorado series; *Km*, Montana series, and *Kl*, Laramie series; *bbr*, basic igneous rock, and *apt*, acidic rock. Length of section about 11 miles. (Livingston, Mont., folio, U. S. Geol. Surv.)

With present data it is impossible to interpret all the deformations at this time in a strictly inductive way, and differences of opinion remain appropriate. A composite interpretation may, however, be indicated. The facts that have just been given relative to folding and overthrust seem to indicate clearly a lateral movement of the crust, attended by a sub-crustal shear, and a folding and faulting of the crustal zone. Using the methods of estimate previously set forth (Vol. II, p. 125), the thickness of crust thus sheared was three or four miles. The fault throw given above (15,000 feet) is what would naturally follow if a crust three miles thick were thrust over the normal surface. Dawson's estimates of shortening and height of the folded portions are closely in harmony with this very instructive faulting phenomenon.

So far as the American continents are concerned, the folding-faulting movement, here interpreted as a shear movement of a shell three or four miles thick, was essentially confined to the western border, but it extended the length of both North and South America. This is probably typical of the great mountain-making movements of post-Cambrian times. Folding seems to have been concentrated along one great belt in each continent for a given continuous direction. This folding is thought to imply shrinking of the earth-body. Dawson's estimate of the shortening involved in the Laramide range alone implies a descent of the surface of four miles. If the shortening involved in the parallel ranges west of the Laramide range be added, the descent of the surface was probably as great as the extreme upward folding of the range, as maintained by Suess.

The shrinkage which is implied by this folding was probably first and chiefly felt by the ocean basins, for reasons set forth previously. The primary effect of this is thought to have been some increase in their capacity as basins, and hence

the withdrawal of the sea from its epicontinental extension. We have avoided calling the emergence of the land an *uplift* on this account. It is not, as we conceive, a mere matter of relativity. The initial act lies with the ocean bottom, and the water seconds this by an actual withdrawal.

But this is not thought to complete the sequence of events. The continental platform is warped in its various parts as it follows the ocean basins in sinking. This seems to have two phases at least. The one is expressed in the facts already

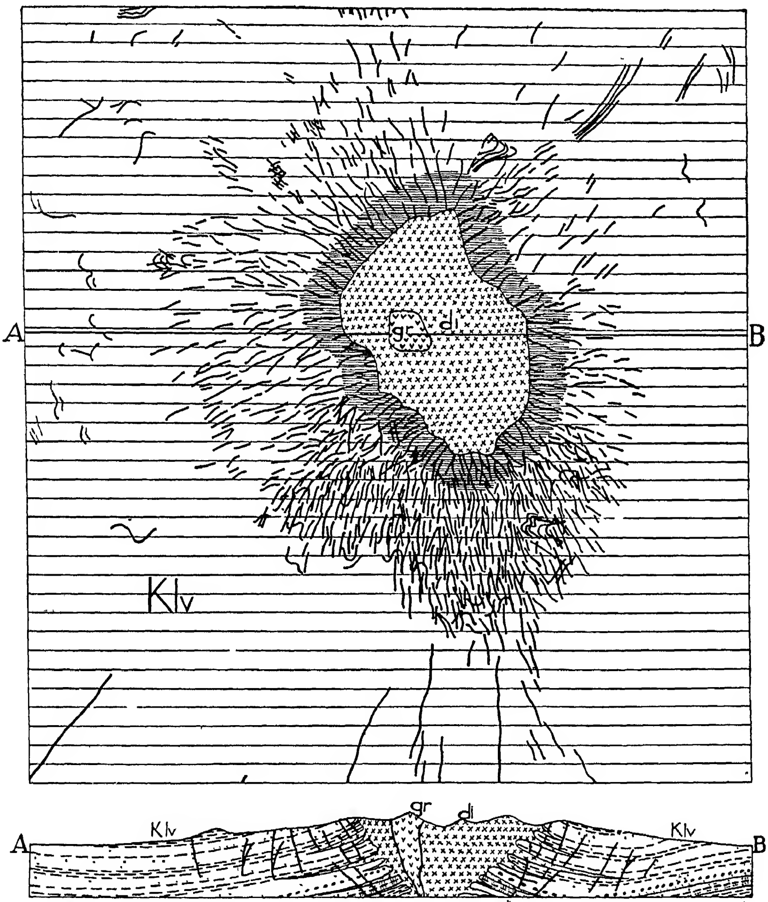


FIG. 406.—Map and section showing relations of igneous rock to the Cretaceous formations in the Crazy Mountains of Montana. The section is along the line *AB* of the map. *Klv*, Livingston formation; *di*, diorite; *gr*, granite. The especial feature of the map is the extraordinary number of dikes radiating from the central intrusion, *di*. The shaded area about *di* represents the zone of contact metamorphism about the intrusion. Length of section about 20 miles. (Livingston and Little Belt, Mont., folios, U. S. Geol. Surv.)

noted, that the epicontinental seas withdraw unequally in different regions, as for example from the eastern Gulf region earlier than from the Atlantic or the western Gulf coasts. The other phase is expressed in the vertical upbowing of certain tracts, usually old mountain tracts, such as the Appalachian in the present case. In general, those borders of a continent that do not suffer crustal shear and folding, are apt to be bowed in this way as a part of the deeper deformation of the continental segment, resulting from its squeezing between the adjoining oceanic segments, as heretofore explained.

The deformations at the close of the Cretaceous seem to have been of the typical earth-body type, expressing themselves in all the characteristic phases—basin sinking, sea withdrawal, crustal shear, folding and faulting, vertical bowing, and general warping.

Igneous eruptions.—The close of the Cretaceous was attended by exceptional igneous activity, the eruptions beginning late in the Laramie epoch. It was during this period of igneous activity that many of the great bodies of igneous rocks of the west, whether extrusive or intrusive, were forced up. Fig. 406 shows the relation of igneous intrusions to Cretaceous beds in the Crazy mountains of Montana. It may be noted in passing, that igneous eruptions occurred in other lands at the same or about the same time, among them the lava-flows of India, the greatest on record.

Upper Cretaceous of other Continents.

Europe.—As shown by the distribution of the Upper Cretaceous strata of Europe, extensive transgressions of the sea occurred at the beginning of this period. What is now the central plateau of France was land during the Earlier Cretaceous (Comanchean) period, but was largely submerged during the Later. So also was much of the great land area of the Earlier Cretaceous period lying northeast of the Paris basin. In Saxony, Silesia, and Bohemia, the Upper Cretaceous system is widespread, and rests on Paleozoic strata, indicating, or at least suggesting, that the submergence was more general for this region than in any earlier period of the Mesozoic. During the closing stages of the Upper Cretaceous, fresh-water beds appear in localities (Alpine region) where marine sedimentation had been in progress, showing that the region was by this time affected by the movements which were to mark the close of the era.

Russia was more extensively under water during the Earlier Cretaceous period than most other parts of Europe, but even here the

Upper Cretaceous beds spread beyond the Lower, having notably greater extension both in the central and southern parts of the country. In central Russia, the uppermost beds of the system have little development, though they are of importance farther south, covering wide areas south of latitude 55°.

As in the case of the Lower Cretaceous, the Upper Cretaceous of southern Europe is notably unlike that of the central province. While

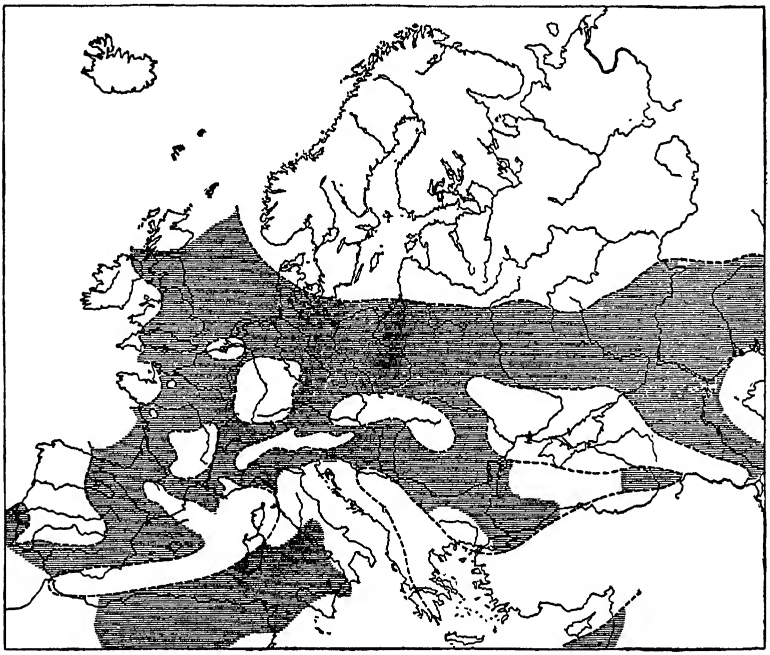


FIG. 407.—Sketch-map of Europe showing the relations of land and sea (shaded area) during the Cenomanian epoch. (After de Lapparent.)

clays and marls are common, limestone is still the dominant formation in the southern province, where clear waters still prevailed. From a characteristic genus of fossils, much of the limestone of the system is known as the Hippurite limestone.

The most notable petrographic feature of the Upper Cretaceous system of Europe is the abundance of chalk. Both in England and France it attains an aggregate thickness of several hundred feet, though much of it is far from pure. It grades into marls and clays on the one hand, and into sandstone on the other. The lowest chalk-beds occur

in the Cenomanian series (p. 109), and the same sort of rock constitutes a part of each of the succeeding series. Chalk is, however, by no means co-extensive with the system, for it has little development outside of the Anglo-French area. The name "Cretaceous," therefore, *as generally used,* is as inappropriate as a name could well be, having no applicability to the Lower Cretaceous, and fitting only a relatively small area of the Upper. Even within the areas where chalk occurs, it is not everywhere the dominant sort of rock.

Greensand occurs in the Upper Cretaceous as well as in the Lower, and iron-ore beds, similar in character and origin to those of the Lower Cretaceous, occur in the Upper. In this case, the ore was derived from the Lower Cretaceous.

The Danian of Europe, sometimes unconformable on the lower parts of the system, is perhaps to be looked upon as recording the transition from the Mesozoic to the Cenozoic.[1] Its fossils, especially those of the plants, have distinct Cenozoic affinities.

Asia.—The submergence of Europe and North America at the beginning of the Upper Cretaceous finds its parallel in other continents. There are extensive areas of Upper Cretaceous (Hippuritic limestone) in southwestern Asia (Arabia, Persia, Afghanistan, Beloochistan, the Himalayas, and Tibet), closely connected with those of Europe on the one hand, and with those of North Africa on the other. The Himalayan region seems to have been still beneath the sea, for Upper Cretaceous formations are found here and there in the mountains at great elevations. Upper Cretaceous greensand has recently been found in the Salt Range of India.[2] South of these marine beds there appears to have been a large tract of land, including much of India, which has been thought to have stretched southwest so as to unite that peninsula with Africa, though the configuration of the sea-bottom does not lend this view much support. Upper Cretaceous beds occur also on the eastern coast of China, and in Japan. In many of these places, they rest on formations older than the Lower Cretaceous, and therefore record geographic changes dating from the beginning or early part of the Upper Cretaceous period. On the other hand, northern Asia, which was largely submerged during the Earlier Cretaceous period, was largely land during the Later.

[1] Geikie, op. cit., p. 1201.

[2] Seeley, Geol. Mag., 1902, p 471.

It was late in the Upper Cretaceous that the extensive lava-flows of the Deccan occurred. These lava-flows, 4000 to 6000 feet in thickness, cover an area of something like 200,000 square miles, and are perhaps the most stupendous outflows of lava recorded in the earth's history. The lavas lie on the eroded surface of the Cenomanian and are interbedded, locally, with sediments of the "uppermost Cretaceous."[1] The fossils of these interbedded sediments show that the lavas were subaërial.

Africa.—In northern Africa the Lower Cretaceous beds were confined to the northwestern mountains, but the Upper Cretaceous beds, which overlie the Lower unconformably,[2] spread southward, and cover most of the desert, indicating great submergence in the north African region at the close of the Earlier Cretaceous period. South of the Sahara, no Upper Cretaceous beds are known except in a few small areas about the coast. Here they rest on crystalline schists, with no Lower Cretaceous beds beneath, or, so far as known, near.

South America.—In South America, the sea invaded eastern Brazil, where marine Upper Cretaceous beds cover and overlap the non-marine Lower Cretaceous. In some parts of Brazil, however, the Upper Cretaceous is represented by fresh-water beds only. Farther west, marine Upper Cretaceous beds (Senonian) rest unconformably on Lower Cretaceous formations, and form the summits of most of the eastern Andes, frequently occurring up to altitudes of 14,000 feet, and sometimes considerably higher. Upper Cretaceous beds also occur in southern Patagonia.[3] There appears to have been great volcanic activity in the Andean system (Chili and Peru) during the Late Cretaceous.

Australia.—The phenomena of Australia are in harmony with those of the other continents. The Upper Cretaceous beds are wide-spread and locally rest on formations older than the Lower Cretaceous. Furthermore, the Upper Cretaceous (the *Desert Sandstone*) is in many places unconformable on the upturned and denuded surface of the Lower Cretaceous, showing that there were deformative movements, as well as movements which changed the relations of sea and land, after the

[1] Medlicott and Blanford, Geology of India; 2d ed. by R. D. Oldham; cited by Geikie, Text-book of Geology, 4th ed., Vol. II, p. 1209. Also Stoliczka, Paleo. Indica., Ser. I, III, V, VI, and VIII (1861–1873).

[2] Kayser, Geologische Formationskunde, p 443.

[3] Wilchens, Centralblatt für Mineralogie, etc., 1904, p. 597.

deposition of the Lower Cretaceous beds, and before the deposition of the Upper. This recalls the relations of the Lower and Upper systems in America. The Upper Cretaceous is represented in New Zealand, where beds of coarse clastics, together with some greensand, are found. There is also some coal in the system, which, as in some parts of western North America, is not sharply differentiated from the Tertiary. The Upper Cretaceous system is also represented in central Borneo[1] and Antarctica.[2]

In general it may be said that there was little marine sedimentation in the Late Cretaceous period north of the parallel 60° north, while the Jurassic and Lower Cretaceous systems are here more widespread. Between the parallels of 20° and 60°, on the other hand, the zone where marine Lower Cretaceous is but slightly developed, the Upper Cretaceous system is widespread. Outside of China, the Upper Cretaceous system is wanting over no considerable land-area within these limits. In the equatorial and south temperate zones, the Upper Cretaceous seas were also expanded much beyond the limits of the waters of the preceding period.

Climate.—The fresh-water fossils of the Upper Cretaceous of central Europe indicate a warm climate, comparable to that of Malaysia.[3] In the eastern Alpine region and beyond, there is a conglomerate formation (Flysch) which will be referred to in connection with the Eocene system. The lower part of the formation is, however, Upper Cretaceous, and its constitution is such as to have suggested glaciation. The suggestion has not been verified.

Life of the (Upper) Cretaceous.

The Land Life.

The carbonaceous deposits which the Cretaceous vegetation contributed to the latest Mesozoic series are quite analogous to those of the Coal Measures of the late Paleozoic, and the Animikean carbonaceous beds of the Proterozoic. They all seem to be expressions of undrained conditions of the land, arising out of the initial unbalancing of a base-level state, preliminary to a marked deformative movement. This, in the case of the Cretaceous, is more particularly true of the closing epoch, the Laramie.

[1] Molengraaf, Geol Mag., 1903, p. 170.

[2] Weller, Jour of Geol., Vol. XI., p. 413.

[3] Neumayr, Erdegeschichte, Bd. II, p. 383.

The vegetation.—At the opening of the (Upper) Cretaceous in America, the angiosperms were in marked dominance, and during the period genera now living became more and more abundant, giving to the whole a distinctly modern aspect. Extinct forms came to occupy a subordinate place. Among these were *Zamites*, *Podozamites*, and *Baiera*, which were common in the previous periods, but disappeared at the close of the Cretaceous. Among the living genera that made their appearance were *Podocarpus*, the dominant pine of the southern hemisphere, *Betula* (birch, Fig. 408, *g*), *Fagus* (beech), *Quercus* (oak, Fig. 408, *e*), *Juglans* (walnut), *Myrica* (tamarisk, mayberry, Fig. 408, *b*), *Artocarpus* (bread-fruit tree), *Platanus* (plane-tree), *Liriodendron* (tulip-tree, Fig. 408, *a*), *Persea* (laurel), *Cinnamomum* (cinnamon), *Acer* (maple), *Ilex* (holly), *Liquidamber* (sweet-gum), *Hedera* (ivy), *Cornus* (cornel), *Nerium* (oleander), and *Viburnum* (wayfaring-tree, arrow-wood, Fig. 408, *f*). Prominent among those that had come over from the Lower Cretaceous were *Ficus* (Fig. 408, *i*), *Sassafras* (Fig. 408, *h*), *Magnolia* (Fig. 408, *c*), and *Sterculia* (flame-tree, Fig. 408, *d*). Among the gymnosperms, there was a notable development of the sequoias, which now embrace the giant trees of California, and there were advances among other conifers. The modern genus *Cycas* was present, and the ginkgo had some prominence, though never a leading type. Worthy of special note was the presence of genera in Europe and the United States which are now confined to the southern hemisphere, as *Eucalyptus* and the pine above mentioned. Some of these remained in the northern regions into the early Cenozoic.

Previous to this period, and in its earlier stages, monocotyledons played but an insignificant part in the floral record, but they now began to assume importance. Many palms were present before the close of the period, some of which at least were closely allied to existing forms. Their presence in northern latitudes implies a mild climate. Of even more interest, because of their relations to the evolution of grazing animals, was the appearance of grasses, which do not, however, appear to have attained prominence thus early. It is worthy of remark here that the Cretaceous revolution in vegetation was not only great as a phytological event, but was at least susceptible of profound influence on zoological evolution, for it brought in new and richer supplies of food in the form of seeds, fruits, and fodder. At present, neither the ferns, equiseta, cycads, nor conifers furnish food

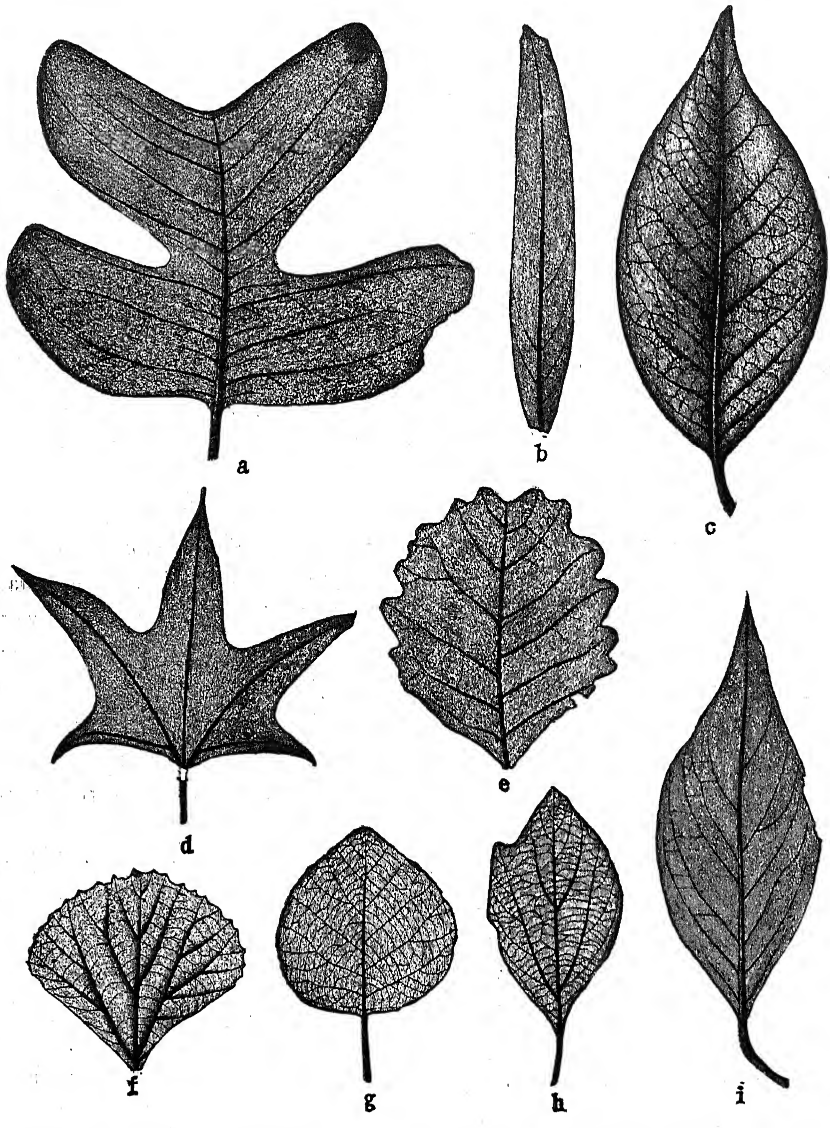


FIG. 408.—A GROUP OF FOSSIL LEAVES OF TYPICAL CRETACEOUS PLANTS FROM THE DAKOTA HORIZON: *a*, *Liriodendron giganteum* Lesq.; *b*, *Myrica longa* Heer; *c*, *Magnolia pseudo-acuminata* Lesq.; *d*, *Sterculia mucronata* Lesq.; *e*, *Quercus suspecta* Lesq.; *f*, *Viburnum inæquilaterale* Lesq.; *g*, *Betulites westi*, var. *subintegrifolius* Lesq.; *h*, *Sassafras subintegrifolium* Lesq.; *i*, *Ficus inæqualis* Lesq.

for any large part of the animal life. The seeds of the conifers are indeed much eaten by certain birds and rodents, but their foliage is little sought by the leading herbivores. The introduction, therefore, of the dicotyledons, the great bearers of fruits and nuts, and of the monocotyledons, the greatest of grain and fodder producers, was the groundwork for a profound evolution of herbiverous and frugiverous land animals, and these in turn, for the development of the animals that prey upon them. A zoological revolution, as extraordinary as the phytological one, might naturally be anticipated, but it did not immediately follow, so far as the record shows. The reptile hordes seem to have roamed through the new forests as they had through the old, without radical modification. The zoological transformation may have been delayed because animals suited to the proper evolution had not then come into contact with the new vegetable realm; but with the opening Tertiary, the anticipated revolution appeared, and swept forward with prodigious rapidity.

The new flora became very widely and uniformly distributed. Not only was the European flora essentially the same as the American, but there was a close resemblance between the flora of Mid-Greenland (70°–72° Lat.) and that of Maryland and Virginia. That there should be no essential variation in a stretch of 35° of latitude implies climatic conditions of remarkable uniformity. The flora, in its general nature, was nearest to that which now flourishes at about 30° latitude, that is, a flora of a sub-tropical type. As this seems to have been attended by low relief of the land, widely extended epicontinental seas, extensive calcareous deposition, and slow consumption of carbon dioxide in rock solution and carbonation, there was present the combination of conditions regarded as favorable for a mild, uniform climate.

The land animals.—The terrestrial animals continued to bear the same general aspect as they did in the Jurassic and Comanchean. In Europe, where the sea made great inroads upon the land, there was some decline in the abundance, variety, and gigantic proportions of the land animals, but in America, where the incursion of the sea was more limited, and where the post-Jurassic deformation of the west made some compensation for sea-advance elsewhere, the land area remained sufficiently large to permit the evolution of the reptilian host to proceed with little restraint. On both continents, however,

the aquatic reptiles seem to have been relatively the more favored, and to have made the greater progress.

The dinosaurs.—These great reptiles still retained the dominant place, but their pre-eminence was less marked than before. The carnivorous forms (*Theropoda*) were less abundant and varied. Among their representatives was the *Lælaps* or *Dryptosaurus*, a leaping, kangaroo-like form with a length of 15 feet.

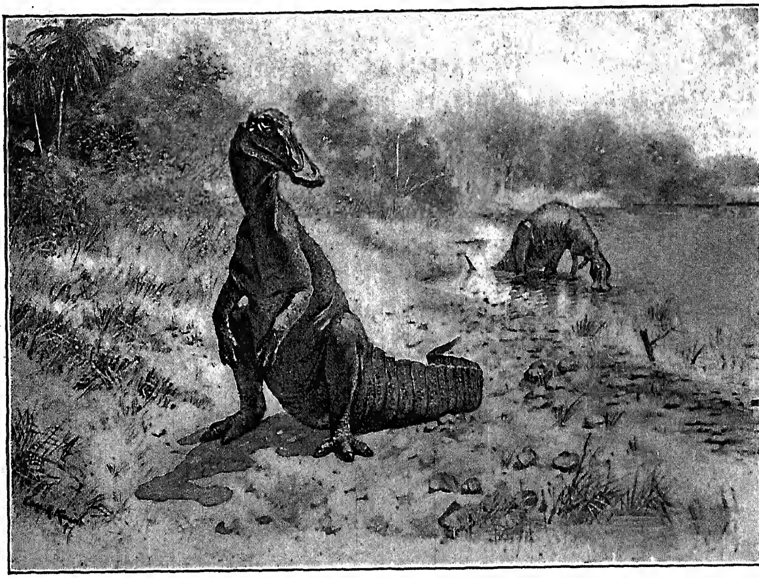


FIG. 409.—Spoonbill Dinosaurs of the Cretaceous (*Hadrosaurus mirabilis* Leidy) as interpreted by Knight. (Osborn, Copyrighted by the Am. Mus. of Nat. Hist.)

The most singular dinosaurian development appeared in the Ceratops family of the herbivorous branch, particularly in the genus *Triceratops* or *Agathaumus* (Fig. 410). These were very large quadrupeds, with enormous skulls which extended backwards over the neck and shoulders in a cape-like flange. Added to this was a sharp, parrot-like beak, a stout horn on the nose, a pair of large pointed horns on the top of the head, and a row of projections around the edge of the cape. One of the larger skulls measured eight feet from the snout to edge of the cape. This excessive provision for defense was not unnaturally accompanied by evidences of low mentality in the form of a very small brain cavity. Marsh remarks that they had the largest

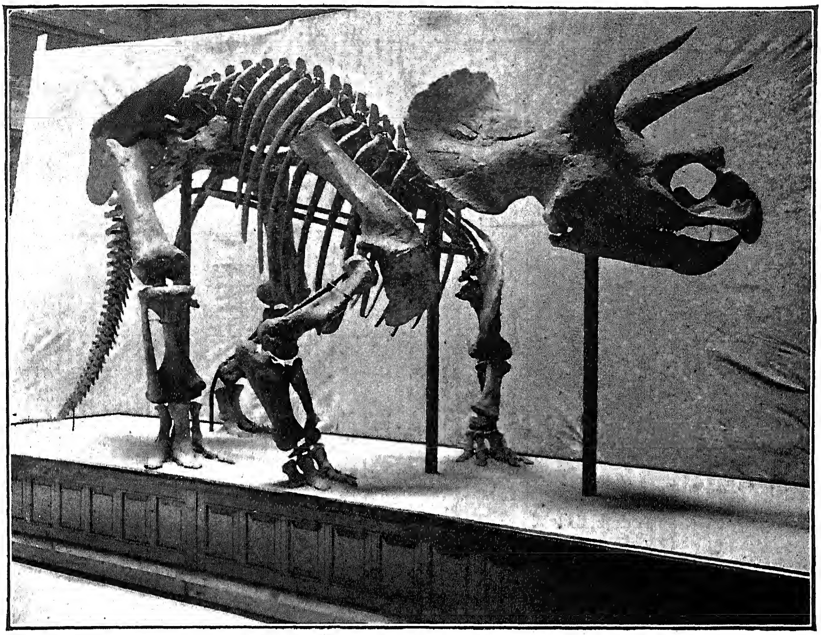


FIG. 410.—Skeleton of *Triceratops prorsus*, Marsh. (U. S. Nat'l Museum.)

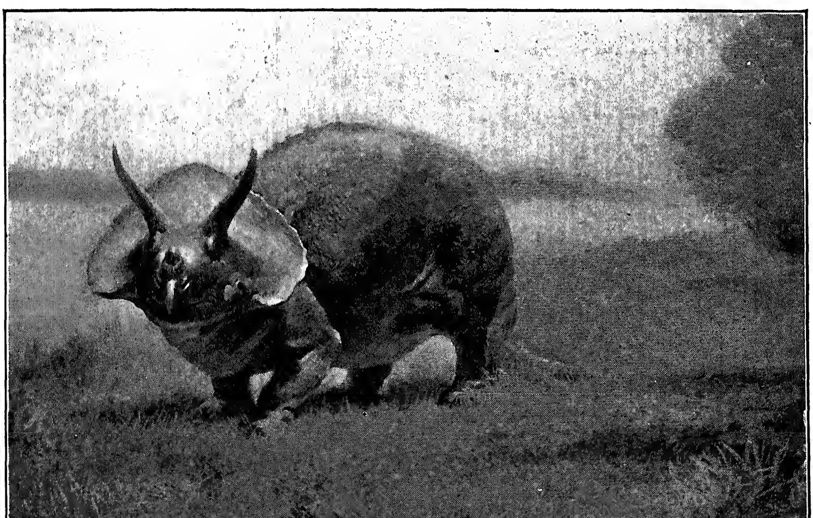


FIG. 410*a*.—*Triceratops prorsus* Marsh, from the Laramie Cretaceous. From a painting by C. R. Knight in the U. S. National Museum.

heads and the smallest brains of the reptile race. They were doubtless stupid and sluggish.

The ornithopod division was represented by *Trachodon, Claosaurus* (Fig. 411) and kindred genera. The posterior parts of all these were strongly developed, the limbs were hollow, and their footprints indicate that they walked in kangaroo-like attitude.

Turtles, lizards, snakes, and crocodiles. —Although it is confidently believed that the *Trionychia,* or river turtles, one of the three or four

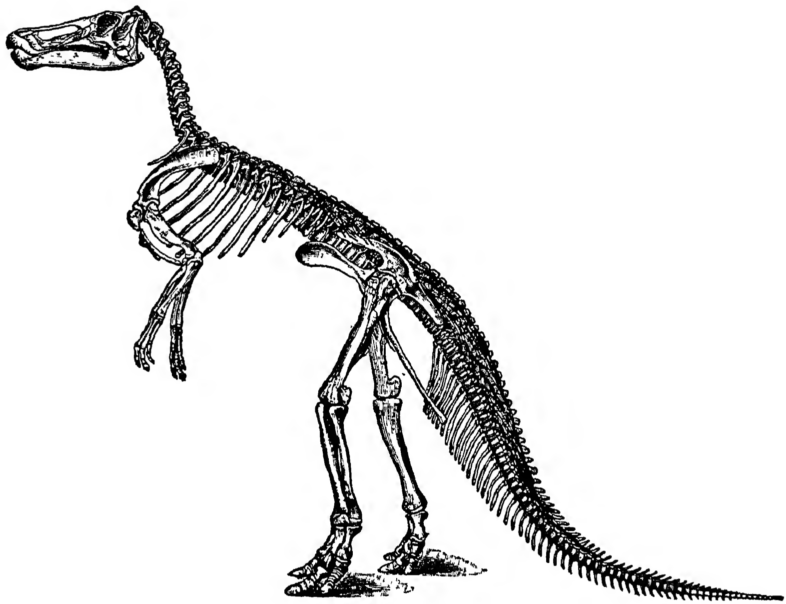


FIG. 411.—A Cretaceous Dinosaur of the ornithopod division, *Claosaurus annectens.* (Restored by Marsh.)

chief divisions of the *Chelonia,* had been differentiated long before, the earliest known representatives of the group are from the Belly River deposits of Canada. Of the true lizards which appeared in the Triassic, the only other Mesozoic form known is one of small size and uncertain affinities from the Laramie. True snakes made their first appearance, so far as known, in the later part of the period, and all were small. Among the crocodiles, the long-snouted teleosaurs (*Teleorhinus)* persisted, in North America at least, until well into the Cretaceous; but for the most part the order underwent a marked change early in the period, developing into the modern type of crocodiles and

gavials. A few small salamanders, of modern type, are known from the late Cretaceous.

The Pterosaurs.—The flying reptiles made so distinct an advance in specialization, that Williston regards them as having come to excel all other volant vertebrate animals. Some attained a wing-spread of perhaps 20 feet, and had great powers of flight. In the genera *Pteranodon* and *Nyctosaurus* (Fig. 412) the development of the anterior parts was disproportionately great, while the posterior parts were very small and weak, so much so that it is doubtful whether they

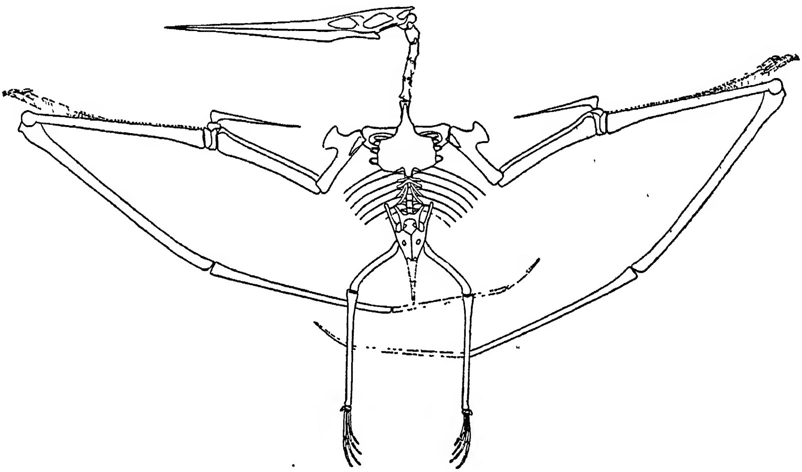


Fig. 412.—A Cretaceous Pterodactyl, *Nyctosaurus gracilis* Marsh, about one-ninth natural size, from Niobrara Cretaceous, Kansas. (Restored by Williston.)

could stand on their feet alone. That they had powerful and sustained means of flight, is implied also by the occurrence of their remains far from shore. In Cretaceous times, they were all short-tailed, and for the most part toothless, though the toothed forms persisted for a while. Their bills resembled those of modern birds, and they have been styled the kingfishers of the Cretaceous seas. If these forms were the sole ones, the pterosaurs might well be classed with the sea life.

Terrestrial birds undoubtedly existed, but the record is negative, while curious aquatic forms appeared, which will be treated under the sea life.

The slight progress of the mammals.—The mammals thus far recovered from the Belly River and Laramie Cretaceous deposits

indicate little advance upon the Jurassic and Wealden forms. The relics are fragments of bones, jaws, and teeth, all of which seem to represent marsupials or monotremes of small size. They appear to have played a very inconspicuous part in the fauna of the period.

The Sea Life.

The sea saurians.—The ichthyosaurs and plesiosaurs which had dominated the Jurassic sea lived on into the Cretaceous, but the ichthyosaurs almost disappeared soon after the beginning of the period, while the plesiosaurs continued through it, attaining their highest development and perhaps their greatest size. They had great diversity of form, and were doubtless equally diverse in habit.

The sea serpents.—The aquatic branch of the scaled saurians (*squamata*) attained great importance during this period, as veritable sea serpents. The dolichosaurs, long-necked, lizard-like reptiles, were present as early as the Comanchean period, and are not known to have lived after the beginning of the (Upper) Cretaceous. They were the forerunners and perhaps the direct ancestors of the pythonomorphs (mosasaurians) (Fig. 413). The name implies that they were serpent-

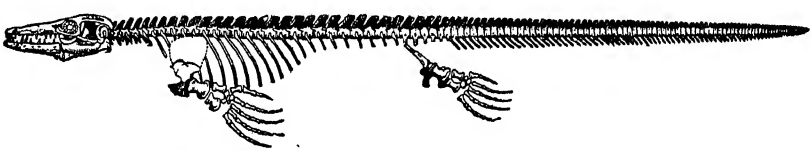


Fig. 413.—A Cretaceous mosasaurid, *Platacarpus coryphæus*, Cope, restored by Williston, from Upper Cretaceous, Kansas.

like in form, but this refers chiefly to the elongation and slenderness of the body. The limbs were retained in less modified forms than those of the ichthyosaurs and plesiosaurs, implying a less complete adaptation to aquatic life. The mosasaurian family flourished in the Cretaceous, and enjoyed a wide distribution, ranging from North and South America to Europe and New Zealand. Their short career seems to have ended with the period, and no direct descendants are known. The plesiosaurs were notably more specialized than in the early Jurassic (Fig. 413, *a*).

The sea turtles.—The first strictly marine turtles appeared in Cretaceous times, and deployed into many and diverse forms. The maximum size of the order was reached in the gigantic *Protostega*

and the even greater *Archelon*. These were broad, flat forms, degenerate in having the carapace reduced to the ribs alone, and probably covered with a soft skin, as are some living marine turtles. *Archelon*

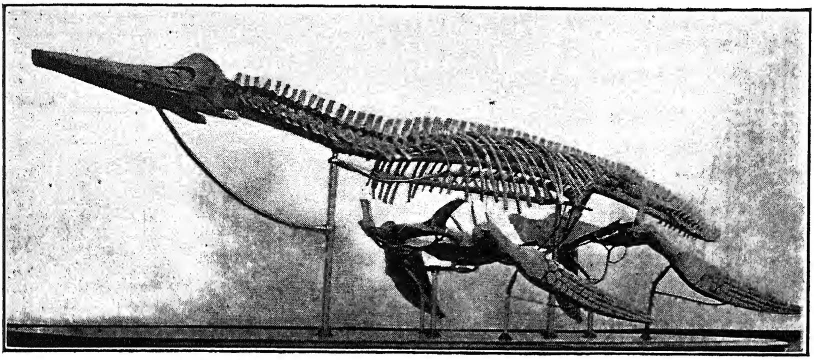


FIG. 413*a*.—*Trinacromerum osborni* Williston. A mounted skeleton of a typical fish-eating plesiosaur, 10 feet long. The elongate head and the shortened neck (Compare Fig. 367) represent specialization characteristic of the late plesiosaurs (Williston). From the Niobrara of Kansas.

had a skull larger than that of a horse, and must have measured fully twelve feet across the shell.

Following the fashion of the day, the rhynchocephalians gave

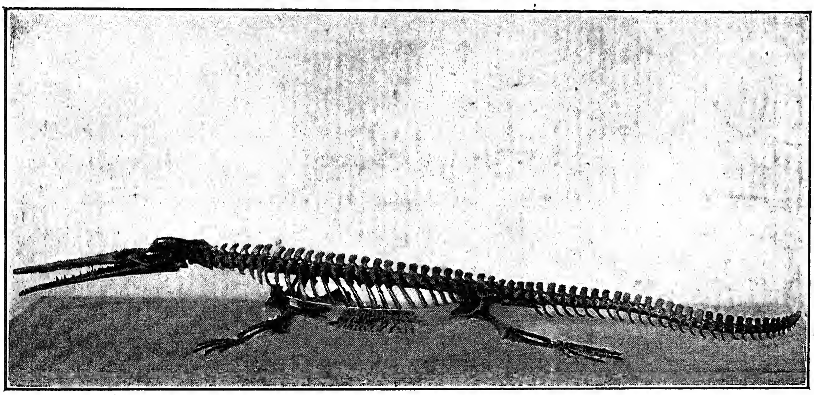


FIG. 414.—*Champsosaurus*, from the Laramie of Montana. Length, about six feet. (After Brown.)

rise to a group of aquatic reptiles, by some considered of ordinal rank (*Choristodera*), represented in Europe and in North America by two closely allied forms, *Simoedosaurus* and *Champsosaurus* (Fig. 414).

The latter began in the Laramie epoch, and continued into the Eocene; the former is known only from the Lower Eocene.

The sea birds.—In the long interval between the first known appearance of birds in the Jurassic, and the later Cretaceous, when they re-appeared, important changes took place, among which was the loss of the elongate, bilaterally feathered tail. The Jurassic birds were ter-

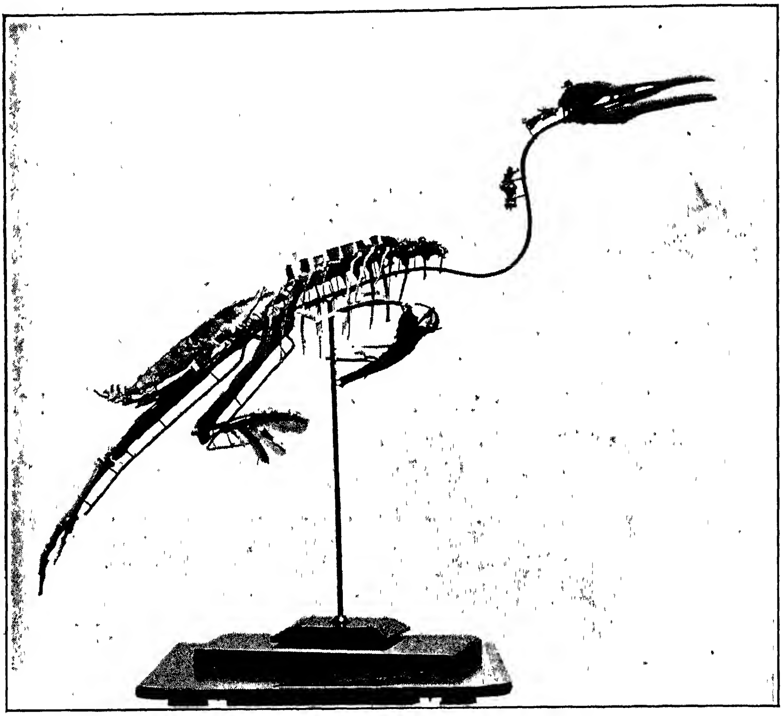


Fig. 415.—*Hesperornis regalis.* Skeleton in U. S. National Museum from which the restoration Fig. 415*a* was made. Sternum and two anterior cervicals supplied by restoration. (Lucas.)

restrial, while the Cretaceous were aquatic. The Cretaceous birds belonged to two widely divergent classes, the one consisting of large flightless birds (*Hesperornis*), the other of small birds of powerful flight (*Ichthyornis*). The *Hesperornis* (Fig. 415), was a large, flightless, highly specialized diver, with aborted wings and remarkable leg development. The wings had almost vanished, a single bone only being left. This implies that, following the evolution which had produced the wings, there was a degenerative history long enough for them to dwindle

almost to the point of extinction. Concurrent with this, and doubtless its cause, was an extraordinary development of the legs by which they became not only very powerful, but their efficiency as paddles was increased by the bones of the foot being so joined to those of the leg as to turn edgewise in the water when brought forward. Not only this, but, strangely enough, the legs were so joined to the body frame as to stand out nearly at right angles to the latter, like a pair of oars, instead of standing under the body as walking legs universally

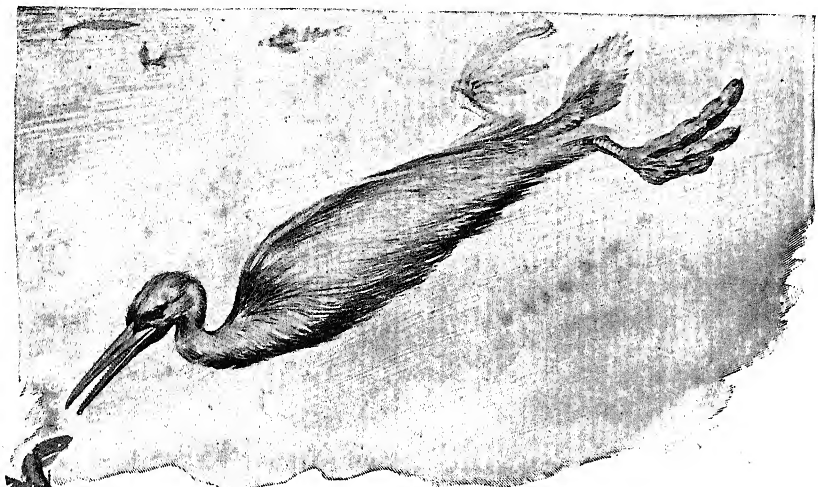


FIG. 415*a*.—Restoration of the great toothed diver of the Cretaceous, *Hesperornis*, by Gleeson, based on a skeleton in the U. S. National Museum. (From Lucas' Animals of the Past; by permission of the Publishers, McClure, Phillips & Co.)

do.[1] Apparently walking as well as flying had been abandoned, and the organism was specialized for swimming and diving only. The head, neck, and body were elongate and admirably shaped for plunging through the water. Favored by the powerful specialized hind limbs, the *Hesperornis* was doubtless a swift swimmer and an expert diver, and must have been a formidable enemy to the sea life on which it chose to feed. Its jaws were armed with teeth set in a groove in primitive saurian fashion, and, like the jaws of snakes, were separable so as to admit large prey. As these strange birds attained a length of six feet in some cases, their victims may have embraced fish and reptiles of considerable size. As they have been found in Kansas, Mon-

[1] Lucas, Animals of the Past, 1901, pp. 81–85.

tana, North Dakota, New Jersey, and England, they probably frequented the continental waters somewhat widely, and belong more to the sea life than to the land life from which they sprang.

The second type, *Ichthyornis* (Fig. 416), consisted of small birds, scarcely larger than pigeons, and tern-like in aspect, endowed with great powers of flight, and armed with teeth set in sockets. In contrast with

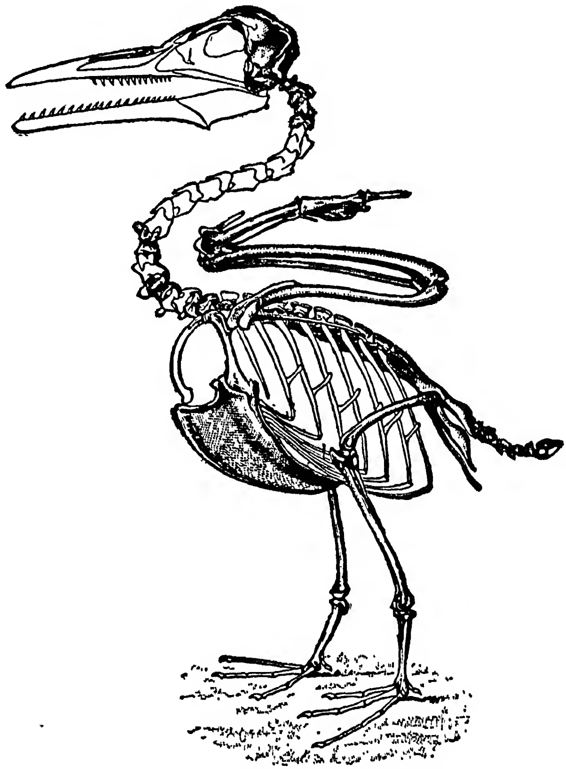


FIG. 416.—*Ichthyornis victor*, a Cretaceous toothed bird of flight, $\frac{1}{6}$ natural size. (Restored by Marsh.)

Hesperornis, the anterior parts, especially the wings and keel, were strongly developed, while the legs and feet were small and slender. Their biconcave vertebræ and other skeletal features, as well as their small brains, show primitive reptilian relations. Their habitat was the same as that of *Hesperornis*, and yet the two were farther apart structurally, than any two types of birds now living (Marsh).

Several genera of birds, embracing altogether about 30 species,

are now known from the Cretaceous; but less than half a dozen of them belong to the *Hesperornis* type.

Compared with the Jurassic *Archæopteryx,* both the *Hesperornis* and *Ichthyornis* show progress in the abbreviation of the long bilaterally feathered tail, and in the loss of the distinct fingers and claws; but, on the other hand, the fish-like vertebræ of *Ichthyornis,* and the groove-set teeth of the *Hesperornis,* are features almost as primitive and reptilian as any possessed by the Jurassic bird. This illustrates, as noted by Marsh, that certain parts of an animal may linger in a primitive condition, while other parts make notable advances. The wide divergence of the two Cretaceous types from one another, and the divergence of both from the Jurassic form, seem to imply that birds had their origin at a much earlier date. What was happening in all this time among the true land birds is almost wholly unknown.

The seaward movement.—From the foregoing, it will be seen that a notable feature of the period was the marked movement of land forms to the sea. Besides the ichthyosaurs and plesiosaurs, whose ancestors were land forms which went down to sea when the Jura-Trias sea extension reduced the land-area, and broadened the shallow seas, there were now added, in this greater period of sea extension and land restriction, the dolichosaurs and pythonomorphs descended from some land form of the scaled reptiles, the sea turtles from the terrestrial chelonians, a marine rhynchocephalian from some land form, and aquatic birds, one form of which was specialized for sea life as perhaps no bird was before or has been since, besides the further marine adaptation of the crocodilians and the pterosaurs, one type of which was also extremely specialized for aquatic life. All this is doubtless but a natural outcome of the prolonged and extensive transgression of the sea upon the face of the continents.

The marine fishes.—A very important change took place in the fish fauna, in the transfer of dominance from the ganoids and other forms of ancient fish to the teleosts, the present prevailing kind. This change set in during the Comanchean, much as did the change in the plants, and was complete by the middle of the Later Cretaceous, thus running singularly apace with the evolution of the angiosperms. It is not easy to see any genetic relationship between these changes, for the teleosts do not seem to be in any notable way dependent on angiospermous vegetation. Though modern in type, the special forms were

yet in the main ancestral, and are now extinct. The sharks and rays were chiefly of the modern types, though not of living species.

The marine invertebrates.—The most notable departure from the precedents of the preceding ages is the prominent place which the rhizopods or foraminifers took in the record. They made large contributions to the distinguishing formation of the period, the chalk, and they were concerned in the formation of the greensand, scarcely less characteristic of the period than the chalk. While these minute organisms live on shallow bottoms, on fixed algæ, and in abysmal water, they are chiefly denizens of the surface waters of the open sea. It is not essential to them that the sea be deep, but in shallow seas the relatively large amount of terrigenous material deposited, the mechanical action of clastic material, and the prevalence of higher forms of life that prey upon them, render the accumulation of their shells in distinctive deposits rare, while in the abysmal waters, where these hostile agencies are essentially absent, foraminiferal oozes are characteristic formations. On this account, it was formerly held that the chalk deposits were of deep-sea origin, and hence implied deep depression of the chalk-areas; and since shallow-water deposits are sometimes intercalated between chalk-beds, profound oscillations of level were freely deduced. But the presence in the chalk of the fossils of shallow-water life, joined to other considerations, has forced the essential abandonment of this view. The relative prominence of the foraminifers becomes all the more curious on this account. The breadth of the epicontinental seas, the lowness of much of the land, and its ample vegetal mantle, sufficiently explain the restriction of clastic competition and the associated destructive action; but they leave the relative scantiness of the usual invertebrate life of clear and shallow seas unexplained. Two suggestions of uncertain value may be offered: (1) the water, though not deep in the abysmal sense, may have been somewhat too deep over the chalk-areas to furnish congenial conditions for most of the invertebrates, and (2) the limitation of the fresh-water supplies of food usually borne out by the rivers may have affected adversely the food-supply upon which the shallow-water invertebrates depend.

Sea-urchins were quite abundant, and lent one of its characteristic aspects to the fauna (Fig. 417, *q–u*), while corals and crinoids, so long associated with clear seas, were not abundant, facts which lend some

support to the first of the above suggestions, since the sea-urchins have considerable range in depth, and forms not unlike those of the Cretaceous are now dredged from deep water.

In the clastic formations, the pelecypods and gastropods furnished a notable and characteristic element (Fig. 417, *j–p*). It will be seen by a glance at the figures that they were making progress in modernization. The cephalopods were still a dominant feature, though the ammonites were in their decline, and were showing erratic divergencies of form attended by much ornamentation similar to that which marked corresponding stages of the trilobites and crinoids. Odd forms of partial uncoiling, or of spiral and other unusual forms of coiling, were striking features. Fig. 417, *e* and *h*, illustrate two of these. The aberrations were not usually systematic, but affected various genera and species, and even the same individuals differently at different stages, some being quite symmetrical up to a certain age, and then becoming erratic; but even this does not hold universally. It lends some little plausibility, however, to the view that these eccentricities mark the senility of the race. An interesting form perhaps to be classed here was the *Baculites*, which resumed the straight form of the primitive *Orthoceras*, while it retained the very complicated suture of the *Ammonites* (Fig. 417, *g*). Typical forms of the ammonoids are shown in Fig. 417, *b*, *c*, *d*, and these are to be regarded as representing the main lines of progress. The belemnites were abundant, represented particularly by *Belemnites* and *Belemnitella*. These also were nearing the end of their race.

Special faunas.—On the Atlantic coast there were, at the north, a series of subfaunas corresponding to the Ripley fauna at the south, and above these (New Jersey and Maryland), there were faunas not found at the south.[1] The earliest faunal group at the north embraced the sub-faunas of the Merchantville, Woodbury, Marshalltown, and Wenonah beds, and corresponded essentially with the fauna of the Matawan formation.[2] In the Merchantville sub-fauna, *Axinea mortoni*, *Idonearca antrosa*, *Trigonia eufaulensis* and *Panopea decisa* are abundant. In the Woodbury beds next above, most of these are rare, and *Cyprimeria*, *Breviarca*, *Lucina cretacea*, *Cancellaria subalta*, and others, rare or absent below, become the commonest species. In the Marshalltown beds, *Trigonia*, *Cyprimeria*, and *Idonearca vulgaris* are abundant, while

[1] See Reports of Maryland and New Jersey.

[2] Weller and Knapp, The Classification of the Upper Cretaceous Formations and Faunas of New Jersey, Jour. Geol. XIII, 1905, pp. 71–84.

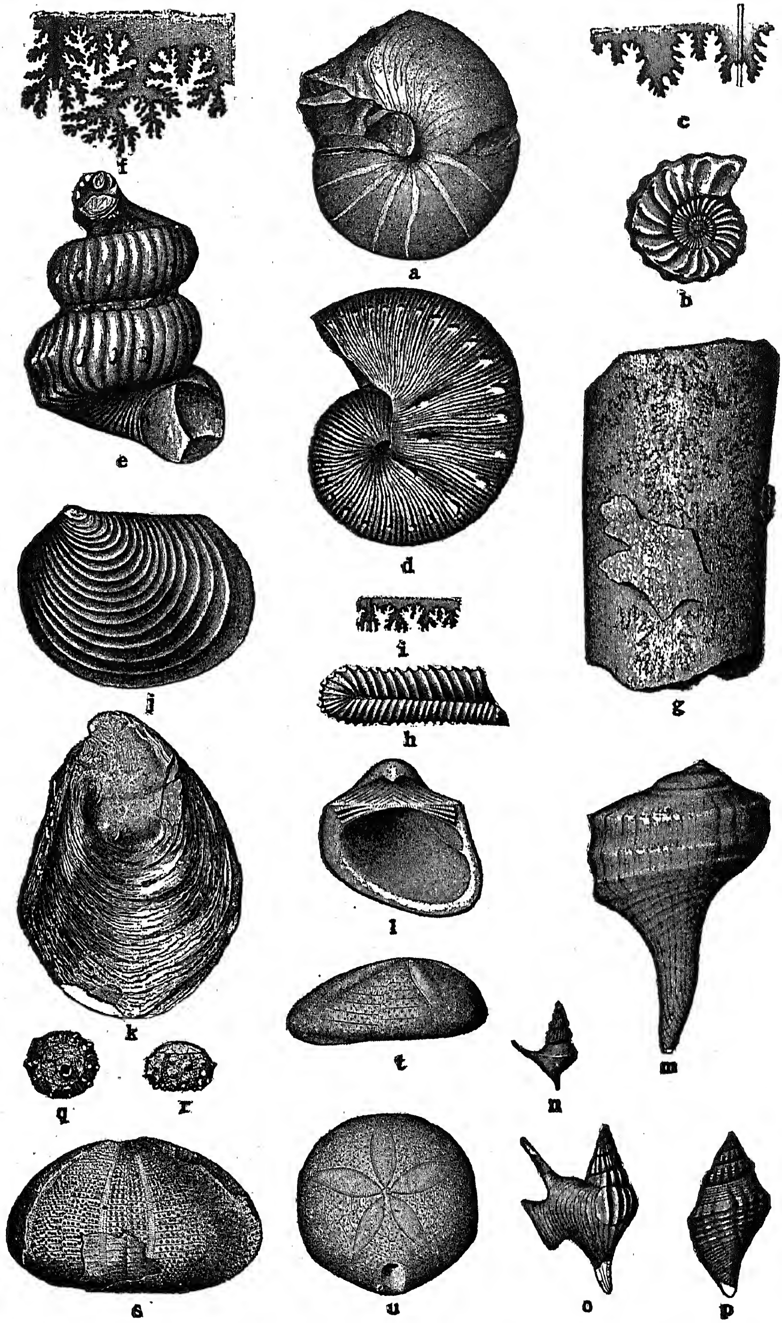


FIG. 417.—CRETACEOUS INVERTEBRATES. (For explanation of figure see p. 189.)

the ponderous *Gryphæa vesicularis* and *Exogyra ponderosa,* with *Ostrea larva* in great abundance, are conspicuous faunal elements. In the Wenonah beds, the uppermost member of the group, there is a return of many of the species of the earliest subfauna, implying that the fluctuations in life were local.

A more marked faunal change then ensued, corresponding approximately to the transition from the Matawan to the Monmouth, in which a new immigrant element is introduced, characterized by *Belemnitella americana* and *Terebratella plicata.* There is at the same time a recurrence of the big oysters, *Gryphæa vesicularis, Exogyra costata,* and *Ostræa larva.* Within the Monmouth formation there are also recurrences of other Matawan species. The above, in a general way, stand for the faunas of the lower portion of the series, south to the Mississippi embayment, including the Eutaw and Ripley faunal groups.

At the north, the Rancocas fauna was characterized by the brachiopod *Terebratula harlani,* associated with many *Gryphæa vesicularis* that lived on from the earlier stages, and, especially in the Vincentown lime sand, by the great numbers of bryozoans and shells of foraminifera. The uppermost horizon, the Manasquan, is characterized by *Caryatis veta* and *Crassatelladela warensis.*

In the Texan province, the lower divisions contain many species common to the faunas of the Atlantic coast, implying close relations. The recurrences of the species above noted are probably but expressions of migrations to and fro in the Atlantic-Gulf coastal tract, as the local conditions varied. The most marked departure from the Atlantic faunas was in the chalk formation (Austin limestone), in which the foraminifers *Textularia* and *Globigerina,* and the sea urchins *Hemiaster* and *Cassidulus,* were important features. The *Inoceramus* and the ammonites also played a much more conspicuous part, and the fauna was otherwise related to that of the great interior sea.

Explanation of Fig. 417.—Cephalopoda. *a, Nautilus meekanus* Whitf., one of the simplest types of closely coiled cephalopods. Note the smooth shell and the simple sutures; *b, c, Prionotropis woolgari* (Mantell), a normal ammonite, with highly ornamented shell and moderately complex sutures; *d, Scaphites nodosus* Owen, an ammonite exhibiting a slight tendency to uncoil in the last volution; *e, f, Helicoceras stevensoni* Whitf., an ammonite coiled in a heliciform spiral, with its highly complicated suture; *g, Baculites grandis* M. and H., a straightened-out ammonite, with a moderately complex suture. In its infantile stage, this form starts as a closely coiled shell; *h, i, Ptychoceras crassum* Whitf., an ammonite which, in the stage shown in the figure, is no longer coiled but recurves upon itself. Pelecypoda: *j, Inoceramus vanuxemi* M. and H., a representative of one of the most characteristic genera of Cretaceous shells; *k, Ostrea soleniscus* Meek, a representative of a genus which with its near allies reached its greatest development in the Cretaceous period; *l, Idonearca nebrascensis* Owen, a shell allied to the arcas of the recent seas. Gastropoda: *m, Pyropsis bairdi* (M. and H.), *n, Drepanochilus nebrascensis* (E. and S.), *o, Aphorrhais prolabiata* (White), *p, Neptunella intertextus* (M. and H.). The canaliculate and modified apertures of these shells differentiate them sharply from the ancient Paleozoic types of gastropods, and suggest some of the shells of recent seas (Compare with Tertiary Figs.). Echinoidea: *q, r, Salenia tumidula* Clark; *s, Pedinopsis pondi* Clark, two forms of regular sea urchins in which the only lack of radial symmetry is in the apical system of plates, as is well shown in *q*; *t, Botriopygus alabamensis* Clark; *u, Cassidulus subquadratus* Con., two sea-urchins in which the bilateral symmetry is strongly developed. (Weller.)

In the interior sea, the ammonoids, the nautiloids, *Inoceramus*, and the oysters were conspicuous forms. The gastropod element was prominent in the Fox Hill stage, and the foraminifers in the chalk deposits. In the Colorado series, *Inoceramus* and several genera of ammonites constitute the most conspicuous element in the fauna, associated however with many forms of pelecypods and gastropods. In the Montana series the faunas much more closely resemble those of the Atlantic border province, a considerable number of identical or closely allied species being common to these faunas and those of New Jersey.

In the Pacific-coast province, the (Upper) Cretaceous faunas are less extensive than those of Comanchean age, but the Cretaceous faunas, like the Comanchean, are quite distinct from the contemporaneous faunas which lived in the more easterly provinces. They include several ammonites of types quite different from those of the interior and the east, besides various genera and species of pelecypods and gastropods.

Note.—From a paper which came to hand after this chapter was in type, it appears that certain beds of Colorado, New Mexico, and Oklahoma, which have usually been regarded as a part of the Dakota formation, are really Comanchean, and of marine origin.[1]

[1] Stanton Jour. of Geol., Vol. XIII.

CHAPTER XVI.

THE EOCENE PERIOD.

The Cenozoic Era.—The remaining periods of geological history constitute the Cenozoic era, the era of modern life. The era is commonly divided into two principal parts, the Tertiary and the Quaternary. These principal divisions are variously subdivided, as shown below:

Cenozoic Era.	Quaternary	Recent, or Human. Post-glacial formations.		
		Pleistocene, or Glacial. Glacial formations and non-glacial deposits of glacial age.		
	Tertiary	Pliocene	Pliocene	Neocene.
		Miocene	Miocene	
		Oligocene		
		Eocene	Eocene	Eocene.

The threefold subdivision of the Tertiary is the one which seems to best fit the phenomena of our continent as now understood, though there is a growing tendency toward the recognition of the Oligocene. This tendency seems to mean that beds are found in our continent which carry fossils similar to those of the Oligocene of Europe, rather than that the Oligocene of this continent constitutes a natural and major subdivision of the Tertiary.

The nominal basis of the Cenozoic classification and nomenclature is a radical departure from that used for earlier eras. Here, stages of approach to existing types of life are made the basis, at least nominally. Originally, Eocene (dawn of the recent) formations were defined by the presence of a few fossils of living species, specifically 3½ per cent, generalized to 5 per cent or less; Miocene (less recent, i.e. less than half the fossils represent living species), defined by about 17 per cent, generalized to mean a minority, of living species; and Pliocene (more recent) by 36 to 95 per cent, interpreted as a majority.

On its face, this classification seems as artificial as the Linnæan classification of plants by the number of their stamens, though it has a somewhat more natu-

ral origin. Certain formations in the London and Paris basins were taken as the type of the Eocene, and they contained $3\frac{1}{2}$ per cent of living species, as then determined. Certain other formations in southern France, containing 17 per cent of recent species, as then determined, were taken as the type of the Miocene, and others in Italy of much larger and varying percentages, as the type of the Pliocene. Dana [1] generalizes the criteria as follows: Eocene, no species, or less than 5 per cent living; Miocene, 20 to 40 per cent living; Pliocene, more than half the species living.

It is not surprising that it was soon found that this scheme did not fit the facts in Germany, and an additional division, Oligocene (few recent), was introduced between Eocene and Miocene, taking something from each. In practice, the criteria have not been closely adhered to, and movement toward a natural system has been in progress; but common consensus of opinion as to what constitutes the true basis of a natural system has not yet been reached, and the movement is not very definitely directed. There are geologists who do not believe that there are natural divisions of *general* applicability, the divisions that are natural for one region being unnatural for other regions. With the qualification that all views must yet be put to the test when the whole world shall have been carefully worked over, and that views now expressed must not be held as authoritative, or even necessarily representative, it is proper that we state our convictions, and their application to the unsettled questions of Cenozoic classification and nomenclature.

We believe that there is a natural basis of time-division, that it is recorded dynamically in the profounder changes of the earth's history, and that its basis is world-wide in its applicability. It is expressed in interruptions of the course of the earth's history. It can hardly take account of all local details, and cannot be applied with minuteness to all localities, since geological history is necessarily continuous. But even a continuous history has its times and seasons, and the pulsations of history are the natural basis for its divisions.

In our view, the fundamental basis for geologic time divisions has its seat in the heart of the earth. Whenever the accumulated stresses within the body of the earth over-match its effective rigidity, a readjustment takes place. The deformative movements begin, for reasons previously set forth, with a depression of the bottoms of the oceanic basins, by which their capacity is increased. The epicontinental waters are correspondingly withdrawn into them. The effect of this is practically universal, and all continents are affected in a similar way and simultaneously. This is the reason why the classification of one continent is also applicable, in its larger features, to another, though the configuration of each individual continent modifies the result of the change, so far as that continent is concerned. The far-reaching effects of such a withdrawal of the sea have been indicated repeatedly in the preceding pages. Foremost among these effects is the profound influence exerted on the evolution of the shallow-water marine life, the most constant and reliable

[1] Manual, 4th ed , p. 880.

of the means of intercontinetal correlation. Second only to this in importance is the influence on terrestrial life through the connections and disconnections that control migration. Springing from the same deformative movements are geographic and topographic changes, affecting not only the land, but also the sea currents. These changes affect the climate directly, and by accelerating or retarding the chemical reactions between the atmosphere, hydrosphere, and lithosphere, affect the constitution of both air and sea, and thus indirectly influence the environment of life, and through it, its evolution. In these deformative movements, therefore, there seems to us to be a universal, simultaneous, and fundamental basis for the subdivision of the earth's history. It is all the more effective and applicable, because it controls the progress of life, which furnishes the most available criteria for its application in detail to the varied rock formations in all quarters of the globe.

The main outstanding question relative to this classification is whether the great deformative movements are periodic rather than continuous, and coöperative rather than compensatory. This can only be settled by comprehensive investigation the world over; but the rapidly accumulating evidence of great base-leveling periods, which require essential freedom from serious body deformation as a necessary condition, has a trenchant bearing on this question. So do the more familiar evidences of great sea transgressions, which may best be interpreted as the consequence of general base-leveling and concurrent sea-filling, abetted by continental creep during a long stage of body quiescence. It is too early to affirm, dogmatically, the dominance in the history of the earth of great deformative movements, separated by long intervals of essential quiet, attended by (1) base-leveling, (2) sea-filling, (3) continental creep, and (4) sea transgression; but it requires little prophetic vision to see a probable demonstration of it in the near future. Subordinate to these grander features of historical progress, there are innumerable minor ones, some of which appear to be rhythmical and systematic, and some irregular and irreducible to order. These give rise to the local epochs and episodes of earth-history, for which strict intercontinental correlation cannot be hoped, and which must be neglected in the general history as but the individualities of the various provinces.

The periods which have been recognized in the Paleozoic and Mesozoic, chiefly on the basis of European and American phenomena, seem to us likely to stand for the whole world, with such emendations as shall come with widening knowledge.

The classification of the Cenozoic is more hampered by the artificiality of its names, by the intricacy of its details, and by the (as yet) imperfect application of the newer modes of investigating and interpreting the phenomena of *the geology of the land*, as distinguished from the older branch, *the geology of the sea*. A large part of the known deposits of the Tertiary are non-marine. They have been interpreted as lacustrine, and the areas of their deposition as lake basins. The Tertiary has even been called the age of lakes. Certain topographic interpretations are necessary to provide the requisite basins, and this

has hampered the whole physiographic conception of the period. It is probable that this conception must be largely abandoned, and the broader view of land aggradation, with lacustrine deposits as an incident, substituted,[1] and with this change will come some emendation of topographic and dynamic interpretations.

In applying a classification based on body deformation, some regard must be had to the fact that while sea-withdrawal, as the result of increased capacity of the sea-basins, is simultaneous the world over, continental deformations and crustal foldings are more local and less nearly synchronous, for there is no agency to combine and equalize their effects as in the case of the basins. Continental deformations must be employed in the classification with some latitude, and correlations based on them cannot be expected to have an equally high order of exactness. Local advances and retreats of the sea due to local warpings must be eliminated or neglected, in a general classification, for the reason that they are local. If an attempt were made to shift the classification of the Tertiary period to the basis here outlined, the changes would not be radical.

After the deformative movements that closed the Mesozoic era, there seems to have followed a rather protracted period of relative quiescence. In the early part of this period, the area of the land was large, and its relief pronounced. Secondary movements of adjustment through minor warpings, creep, and gradation were in notable progress. During the later portion of the period, the effects of these adjustments were felt in some notable extension of the sea over the lower portions of the continental platforms. For North America this transgression of the sea is represented in Fig. 418. The most notable feature was the extension of the sea in the Mississippi embayment, represented by the formations to be described later. This advance of the sea did not rival the great transgressions of the Cretaceous and Jurassic periods, but the Atlantic and Pacific seem to have joined between the two Americas, and the climatic effects of a dominantly marine period seem to have prevailed, as indicated by the warm-temperate life in middle and high latitudes. All of this seems to constitute a natural period, embracing what is included in the Eocene and the Lower Oligocene (Vicksburgian).

In North America, this period was closed by a withdrawal of the sea from both the Atlantic and Pacific borders of the continent, and by notable crustal deformations in some parts of the western mountain region. At the same time, Florida, which had been submerged and the site of calcareous sedimentation, was partly emerged. Farther south, the changes were even more important, for they appear to have interrupted the connection between the Atlantic and

[1] See Davis, Science, N. S., Vol. VI, p. 619, 1897, and Proc. Am. Acad. Arts and Sci., Vol. XXXV, p. 345, 1900; and Mus. Comp. Zool.-Geol. Surv., Vol. VI, pp. 43, 45–7, and 48; Gilbert, Pueblo folio, U. S. Geol. Surv , 1897, and Nat. Geog. Mag. Vol. IX, pp. 308–317, 1898; Matthew, Am Nat., Vol. XXXIII, p. 403, 1899; Hatcher, Proc. Am. Phil. Soc., Vol. XLI, 1902, Rev. Jour. of Geol., Vol. XI, p. 92, and Johnson, W. D., 21st Ann. Rept. U. S. Geol. Surv., Pt. IV.

the Pacific in tropical latitudes, diverting the equatorial current of the Atlantic to the northern part of that ocean. These changes, with their attendant effects on climate, influenced the character and distribution of the life. The initial bowing of the Pyrenees and some other mountains in southern Europe is assigned to this time. It is therefore tentatively assumed that there was a sufficiently general deformative movement at the close of the Eocene to mark the end of a a natural period.

The time occupied in these movements and in the secondary results which immediately followed may be regarded as a transitional stage, and referred to the *Oligocene*, with the rank of an *epoch* rather than a *period*. In the lower Mississippi region, the deposition of this epoch took on a terrestrial and a marine phase, the terrestrial recorded by a part of the Grand Gulf beds, containing land plants with occasional fresh-water molluscs; the marine by the Chattahoochie formation. Inland, the White River beds of the Great plains are referred to the same epoch. Matthew[1] urges that these are of eolian origin, practically an ancient loess, which, if true, implies something of aridity in the west, a condition in harmony with the rapid evolution of the solid-hoofed animals adapted to dry plains, with the gypseous deposits in the Grand Gulf series, and with the notable gypsum formations of the Paris basin, referred to the Oligocene. In these are seen the natural consequences of an epoch of land extension.

The true Miocene, according to Dall,[2] was ushered in by a marked change in the temperature of the waters of the Atlantic coast, attributed to a northern current, and resulting in the sharpest faunal change in the Tertiary series of the Atlantic coast. Apparently this must mean more than a mere shifting of preëxisting currents, for a cold current so far south can hardly be referred to North Atlantic waters, when magnolias and many other trees now confined to the warm temperate zone were growing in Greenland and the Arctic regions generally. Heer has identified a large flora of forms that now imply a temperate climate, in latitudes of 60° to 80°, which he refers to the Miocene.[3] The correctness of this reference is questioned on other grounds, and the cold Miocene current on the southern coast of the United States, colder than that of to-day, makes such a reference highly improbable. The Miocene cold current seems to imply an important climatic change affecting the north Atlantic, and adds strength to the evidences above cited of the deformative action closing the Eocene. The flora of Europe referred to the early Miocene is not in harmony with this supposed cooler condition, since it embraces forms now representative of warm latitudes; but during the period a marked change in the direction of the existing flora took place.

During the Miocene, the sea again advanced upon the land on both the Atlantic and Pacific coasts, though not greatly beyond the present limits, and chiefly in the Maryland-California latitudes; hence this may be regarded as an inter-deformative stage, and as extending to the next general deformative movement.

[1] Am. Nat., Vol. XXXIII, p. 403, 1899.

[2] 18th Ann. Rept. U. S. Geol. Surv., 1898, p. 329; see also other papers *postea*.

[3] Flora Fossilis Arctica, Vol. I, pp. 161–166.

The next deformative movement was one of the greatest in post-Cambrian history, and appears to have involved some movement of nearly every mountain range whose history is known, as well as a very marked withdrawal of the sea, as indicated by buried or submerged erosion channels traversing the continental shelves. *These are not however regarded as indicating an elevation of the continent equal to their depth below the present sea-level,* but chiefly as indicating flexures of the continental border attending the deformative movement; even thus interpreted they imply sea-withdrawal. This great deformation is held to give a better definition to the Pliocene period than any assigned percentage of living and extinct shells in the sediments of the time. The extinction of species during this period seems to have been greatly lessened by reason of the extinctions and adaptations which had already been brought about by the Oligocene movements and the Miocene cold currents; hence the importance of these changes is not fully revealed in the immediate faunal change. Their biological influence can only be fully measured when the secondary effects, through climatic and other means, have worked themselves out, and this will require a long period, a part of which is still in the future.

An immediate secondary effect is probably found in the glacial invasions which, because of their great influence in the history of the land, have been regarded as constituting a period by themselves, the Pleistocene. In a strict deformative classification, however, this should be united with the Pliocene, for important movements seem to have been in progress during the glacial period, and perhaps the same may be said of the present.

It should perhaps be repeated that this deformative, dynamic classification is not in accord, in all its details, with the classification by species percentage, even in its modified form; but there is no serious discrepancy between them, and if the dynamical considerations shall be supported by future extensions of knowledge in the less known regions of the earth, the existing rather arbitrary classification may easily merge into the dynamical one.

FORMATIONS AND PHYSICAL HISTORY OF THE EOCENE.[1]

The formations of the Eocene system are found in widely separated parts of the North American continent (Fig: 418), but they do not appear at the surface over extensive areas. Within the continental area, their extent was not great at the outset, and in many places they are concealed by younger beds. They include (1) beds laid down in the sea or below sea-level, and (2) beds deposited on the land. The former include formations of (*a*) marine, and (*b*) brack-

[1] For review of all the literature of the Eocene of the continent up to 1891, see Clark, Bull. 83, U. S. Geol. Surv For later publications, see Bulls. 130, 135, 146, 153, 156, 162, 172 and 177. See also article by Dall in 18th Ann., U. S. Geol. Surv., Pt. II, where bibliography up to 1898, is given.

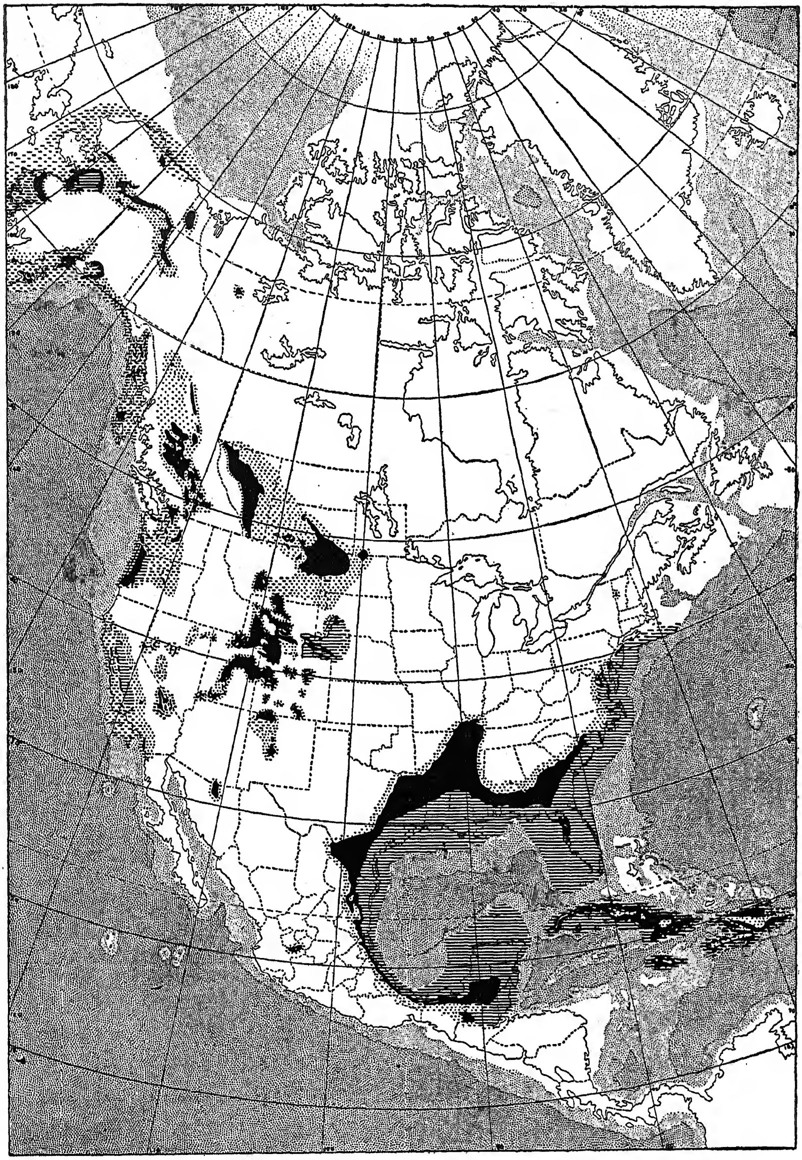


FIG. 418.—Map showing the distribution of the Eocene formations in North America. The conventions are the same as in former maps.

ish-water origin, and the latter those of (*a*) lacustrine, and (*b*) subaërial origin (fluvial, pluvial, eolian). The last are probably more important than has commonly been recognized.

The marine Eocene beds are confined to the borders of the continent; the brackish-water formations are known in Washington and Oregon, while the lacustrine and subaërial deposits are found in many places in the mountains of the west, and on the plains adjacent to them.

The Eocene formations are like the Cretaceous in that they are, in most parts of the continent, largely unindurated. Many of them are still in the condition of sand, gravel, clay, etc., much as when deposited. Locally, they have been indurated, and still more locally, metamorphosed.

The Eastern Coast.

The Atlantic coast.—The Eocene formations of the Atlantic and Gulf coasts appear at the surface at intervals along a belt of varying width from New Jersey to Texas. The beds dip toward the coast (Fig. 380), and from the areas where they appear at the surface, they are continued seaward beneath younger beds.

In the Atlantic Coastal plain, the Eocene beds are separated from the underlying Cretaceous, by an unconformity. They represent the incursion of the sea over at least a narrow area from which it had withdrawn at the close of the Mesozoic. The materials of the Eocene appear to have been derived largely from the Cretaceous, but sediments from farther inland were contributed by the drainage from the highlands and mountains to the west. Clays, sands, and greensand (glauconitic) marls are the most common materials of the Eocene of this province, and the conditions of sedimentation appear to have been much the same as during the Cretaceous.

Until recently, attempts to correlate the Eocene sections of the different parts of the Atlantic and Gulf coasts were not altogether successful, and it is still common to speak of the Lower, Middle, and Upper portions of the system in a rather general way.

In New Jersey (Shark River marl) [1] and Maryland [2] (Aquia and

[1] Ann. Rept. State Geologist of New Jersey for 1893 and earlier years.

[2] Clark and Martin, Maryland Geol. Surv., Volume on the Eocene. The Eocene of this region is sometimes called the Pamunkey series.

Nanjemoy formations), the Lower Eocene only is represented in the exposed beds referred to this period. In Virginia, the Middle Eocene is also present, and in the Carolinas, the system is still more complete (Buhrstone, Santee, Cooper, the last sometimes classed as Oligocene), though the oldest Eocene beds are thought to be wanting. In Florida, the Upper Eocene only is exposed. The interpretation of these variations will be readily made.

The Gulf border.—The Eocene system is more fully represented in the Gulf region than along the Atlantic coast, and the Lower, Middle, and Upper divisions are more clearly defined. Their aggregate thickness is not less than 1700 feet (maximum), of which something like half belongs to the Lower Eocene, and more than half of the remainder to the Middle.

The section in Alabama, which may be taken as fairly typical of the Gulf Eocene, is as follows:[1]

Upper Eocene	White limestone (Jackson and Vicksburg, the latter sometimes classed as Oligocene)	350	feet.
Middle Eocene	The Claiborne series:		
	Claiborne formation, mainly clays and sands, calcareous and glauconitic	140	"
	Buhrstone formation, mainly sand with some glauconite	300	"
Lower Eocene	The Lignitic formation, mainly sands and lignite (Chickasaw)	900	" ±
	The Clayton (or Midway) formation, mainly limestone	10–200	"

It is on the basis of the Eocene of this region that the following classification has been suggested for the Eocene of the east:[2]

(*a*)	Jacksonian	Upper.
(*b*)	Claibornian	Middle.
(*c*)	Chickasawan	Lower.
(*d*)	Midwayan	Lower.

The relations of the Eocene strata to the Cretaceous[3] are much the same in the eastern Gulf States as on the Atlantic coast. They outcrop in a belt just south of that where the Cretaceous beds appear,

[1] Smith, Geol. Survey of Alabama, 1894.

[2] Dall, 18th Ann. Rept. U. S. Geol. Surv., Pt. II. This classification places the Vicksburg in the Oligocene, instead of associating it with the Jacksonian. There appears to be no *physical* reason for this separation.

[3] Smith, Geol. Surv. of Alabama, 1894.

and dip seaward, disappearing beneath younger formations. As along the Atlantic coast, the Eocene sediments seem to have been derived largely from the Cretaceous; but this is not true of all parts of the system, for about the lower Mississippi, much of the Lower Eocene is lignitic, while the Upper Eocene (in Mississippi and Alabama) is composed largely of limestone. A great bay or estuary appears to have occupied the site of the lower part of the Mississippi as far north as the mouth of the Ohio, and in this embayment the deposits extend much farther north than elsewhere. The Lower Eocene (Lignitic formation) extends farther north than the later beds.

Western Gulf region.—The Texas Eocene,[1] which sometimes appears to be conformable with the Cretaceous, is composed chiefly of shallow-water marine deposits; but lignite, and gypsiferous and saliferous sediments recur at various horizons, showing the recurrence of terrestrial and non-marine conditions within the general area of deposition. Iron ore and silicified wood are of common occurrence in connection with the lignite. There are numerous local unconformities in the system, suggesting recurrent changes in the conditions and areas of sedimentation. The Lower and Middle series are represented, and probably the Upper, though there is difference of opinion as to the upper limit of the system in this region.[2] The system attains a thickness of several hundred (800 at least) feet. Various names are applied to different parts of the system in different parts of the State. The fossils are such as to suggest that shallow-water marine life was able to find its way from the Gulf to the Pacific, and vice versa, during this period.

The Eocene of Texas and Louisiana is continued northward into Arkansas, where the Lower and Middle divisions, and perhaps the Upper, are found.[3]

The Pacific Coast.

The changes which marked the close of the Mesozoic era resulted in the exclusion of the sea from most of that part of the present land

[1] Dumble, Jour. of Geol., Vol II. See also Reports of the Texas Geological Survey, and the Austin and Uvalde folios, U. S. Geol. Surv.

[2] Texas Geol Surv.; Hayes and Kennedy. Bull. 212, U. S. Geol. Surv., pp. 22, 23; Smith and Aldrich. Science, New Series, Vol. 16, pp. 836–9, and Vol. 18, p. 26; Dall, Science, Vol. 16, p. 946 and 18th Ann. Rept., Pt. II, U. S. Geol. Surv.

[3] Harris, Arkansas Geol Surv., Vol. II, 1892.

area which had been submerged in the Cretaceous period. This is shown by the wide-spread unconformity between the Eocene and the Cretaceous systems. During the interval of emergence, great thicknesses of sedimentary rocks were removed, and when the sea again advanced upon the land in the Eocene period, sediments were laid down on an eroded surface, which in some places had been reduced toward planeness by subaërial denudation.

Marine formations are wide-spread in California west of the Sierra and south of the Klamath mountains, and in Oregon north of the Klamath mountains and west of the Cascades, but they have little development within the land-area farther north. Various names have been applied to the system and to its parts in different localities.

Marine beds.—The Eocene beds of central California are known as the Tejon series, though other names (e.g. Martinez) have been applied to various parts. The Tejon series is best known in the southern part of the great valley of California, then occupied by the sea, and is well exposed on the east side of the Coast range. It does not appear in the Sierras, or in the northern part of the central valley. In some places the Tejon series lies on the Chico with apparent conformity, though unconformity is more common. Even where there appears to be conformity, the bottom of the Tejon is thought not to represent the oldest Eocene. In the middle part of the Coast range of California, where the Tejon series is more than 4000 feet thick,[1] it is overlain conformably by the Miocene. The Tejon series is mainly clastic, but locally contains lignite, and still more locally, oil.[2] In the Santa Cruz mountains, Eocene beds constitute a part of the metamorphic Pascadero series.[3] In some parts of southern California, the thickness of the Eocene (Escondido series[4]) is estimated at more than 7000 feet, the material being partly sedimentary and partly igneous. A bed of gypsum, thick enough to be of commercial value, is found in this series, and points to the absence of true marine conditions, at least locally and temporarily. Eocene beds are absent from much of northern California and southern Oregon.[5]

[1] Lawson, Science, Vol. XV, 1902, p. 416.
[2] Eldridge, Bull. 213, U. S. Geol. Surv., p. 306.
[3] Ashley, Jour. of Geol., Vol. III, p. 434.
[4] Hershey, Am. Geol., Vol. XXIX, pp. 349–72.
[5] Diller, Bull. Geol. Soc. Am., Vol. IV, p. 220.

Marine Eocene beds (Arago), resting unconformably on the Cretaceous, are wide-spread in western Oregon. They attain great thickness (said to be 10,000 feet[1]), and make up the mass of the Coast

FIG. 419.—Section showing the structure of the Eocene in western Oregon. *Eb*, Eocene basalt; *Ep* (Pulaski formation), and *Ec* (Coaledo formation), Eocene. Length of section about 20 miles. (Diller, Coos Bay, Ore. folio, U. S. Geol. Surv.)

range of that State.[2] The sediments which compose them appear to have come from the Klamath mountains. Various beds of marine Eocene in Oregon, not definitely correlated, have, as in California, received local names (Umpqua, Tyee,[3] Pulaski,[4] etc.). The structure of the Eocene at certain points in Oregon is shown by Figs. 419 and and 420.

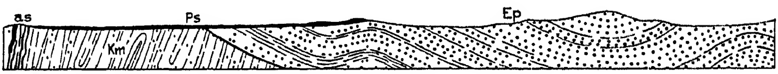


FIG. 420.—Section a little south of the last, showing the relation of the Eocene (*Ep*, Pulaski formation) to the Cretaceous (*Km*, Myrtle formation). *as*, amphibolite schist, and *Ps*, Quaternary marine sand. (Coos Bay folio, U. S. Geol. Surv.)

Brackish-water beds.—By the beginning of the Eocene, the Puget Sound depression, possibly to be correlated with the great valley of California and the Gulf of California, had begun to show itself.[5] The Olympic and Cascade mountain regions on either side of the sound were high, but not mountainous land; and the region of the sound was a great estuary, in and about which deposition was in progress. The sediments accumulated in part at least in brackish water, and resulted in the thick (estimated at 10,000 to 20,000 feet) coal-bearing Puget formation or series of Washington, the upper part of which may be Oligocene or even Miocene.[6] The conditions of sedimentation varied considerably during the deposition of this series, as the numerous coal seams show. Of the coal-beds, 125 are said to be thick

[1] Diller, Coos Bay, Ore, folio, U S. Geol Surv.

[2] Roseburg, Ore., folio, U. S. Geol. Surv.

[3] Diller, Roseburg, Ore., folio, U. S. Geol. Surv.

[4] Diller, Coos Bay, Ore, folio, U. S. Geol. Surv.

[5] Willis, Tacoma Folio, U. S. Geol. Surv.

[6] Willis, Bull. Geol Soc. Am. Vol. IX, 1897–8. See also 18th Ann. Rept. U. S. Geol. Surv. Also Landes, Washington Geol Surv, Vol II, p. 170.

enough to attract prospectors. They range from one to sixty feet in thickness. Most of the workable coal is in the lowest 3000 feet of the series. The Eocene period in this region seems to have been one of interrupted submergence. The area of deposition extended south into western Oregon, and as far east as the Cascade mountains. In the Coos Bay region of Oregon, the Ccaledo formation (Fig. 419), like the Puget formation farther north, contains workable beds of coal and many beds containing brackish-water fossils.[1]

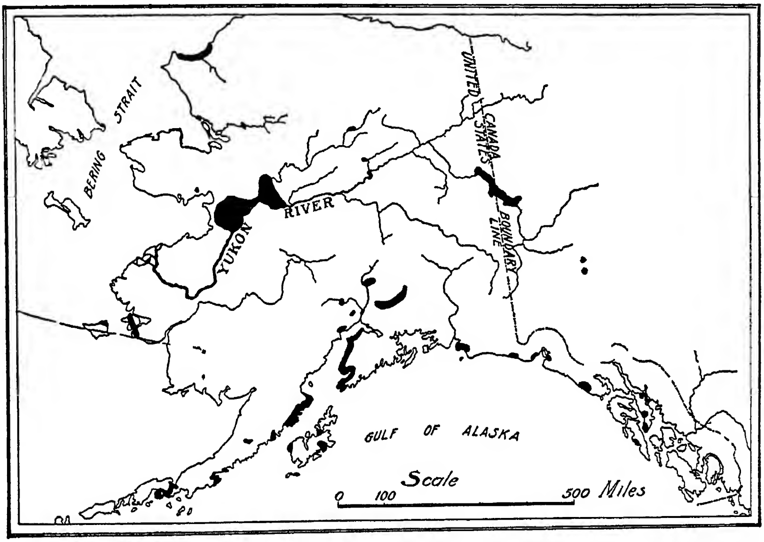


Fig. 421.—Map showing the position of known coal-bearing formations in Alaska. The coal of the Yukon basin is partly Cretaceous and partly Tertiary; that of southeastern and southwestern Alaska, chiefly Eocene, that of the northwest coast, Mesozoic. South of Cape Lisburne there are outcrops of Paleozoic coal-bearing formations. There is also much lignite of post-Eocene age. (Brooks, U. S. Geol Surv)

North of Washington.—British Columbia appears to have been land during the Eocene period, and the erosion there in progress resulted, by the end of the period, in a peneplain which has since been elevated 2000 to 3000 feet.[2] Eocene beds, much disturbed, have been recognized in Alaska,[3] where they are sometimes coal-bearing.

[1] Diller, Coos Bay, Ore., Folio, U. S. Geol. Surv.

[2] Dawson, Science, Vol. XIII, 1901, p. 401. Also Spencer, A. C., Bull. Geol. Soc. of Am., Vol. XIV, p. 131.

[3] Dall, Tertiary Fauna of Florida, Trans. Wagner Free Inst., Vol. III, Pt. VI, 1903, p. 1548.

Terrestrial Formations.

The great warpings and faultings, and the extensive intrusions and extrusions of lava which marked the close of the Mesozoic era in the western part of North America, appear to have developed lands which were relatively high, in association with tracts which were relatively low. The mountain folds, the fault scarps, and the volcanic piles seem to have afforded the elevations necessary for rapid erosion, while the associated valleys and basins and plains furnished lodgment areas for such sediments as the streams, descending from the steep slopes above, were unable to carry across tracts of low gradient. Sedimentation on the land was therefore a feature of the Eocene period, as it has been of all subsequent time. Among the accessible formations of this and all later periods, those of terrestrial origin are far more widespread than those of marine origin.

The terrestrial sedimentation of the Eocene period was probably comparable to that of the present time, though the western mountains had not then attained their present height. Then as now, temporary and permanent streams were doubtless aggrading their valleys, and building fans and alluvial plains where the appropriate conditions were found, while sheet-floods spread débris washed down from the higher lands on the tracts below. The deformative movements which initiated the modern era probably gave rise to basins here and there, in which lakes were formed, and the flows of lava from the unnumbered vents of the time doubtless sometimes obstructed valleys, ponding the streams and giving rise to lakes. Under these conditions, it is probable that much of the débris which was started seaward by the swift waters of the higher lands found lodgment long before it reached the sea, some of it at the bases of steep slopes, some of it on river plains, and some of it in lakes. The wind also made its contribution. The result was an inextricable combination of fluvial, pluvial, eolian, and lacustral deposits.

Terrestrial formations of Eocene age and of fluvial, pluvial, lacustral, and eolian origin are widespread throughout the western interior, occurring even in proximity to the western coast. Many of them are of limited extent, while others are spread over great areas. Since the changes which gave rise to the conditions favoring aggradation on the land continued, at least intermittently, during the period, the

principal sources of sediment and the sites of its lodgment shifted somewhat from time to time, and among the scattered deposits referred to this period, there are notable differences of age. Several more or less distinct stages of deposition have been recognized, the distinctions being based partly on the superposition of the beds, and partly on the fossils which they contain.[1] These several stages are not readily correlated with those of the coastal regions, since synchrony is not readily established between formations containing marine fossils on the one hand, and those containing terrestrial fossils on the other.

1. The oldest recognized stage of the Eocene in the western interior is the *Fort Union* (perhaps corresponding to the Midwayan, p. 199). During this stage, there was an extensive area of aggradation in parts of North Dakota[2] and Montana, and a still larger area in Canada, where the sediments which constitute the Fort Union beds were deposited. These beds, composed of sand, clay, etc., are said to be locally 2000 feet or more thick, and have usually been described as lacustrine. The presence of fresh-water shells (unios, etc.), is consistent with this conclusion for some parts of the formation; but the abundance of the leaves at many places is quite as suggestive of subaërial aggradation for other parts.[3]

The Fort Union beds overlie the Livingston formation (p. 159) conformably,[4] and have been thought, on the basis of their fossils, to represent the oldest Eocene formations of the interior. It will be remembered however that the youngest formations referred to under the Laramie (Arapahoe, Denver, Livingston, etc., p. 158), were deposited in fresh water or brackish lakes, or on land, and that their reference to the Laramie instead of the Eocene, is of doubtful propriety. At any rate, the time of terrestrial aggradation, so characteristic of the Cenozoic era in the western part of North America, had

[1] For an account of the deposits near the 40th parallel, see King's Report, Vol. I, already cited. For the latest attempt at correlating the several lake formations, see Dall, 18th Ann. Rept., U. S. Geol. Surv., Pt. II. See also J. H. Smith, Jour. Geol., Vol. VIII, pp. 444–471.

[2] Wilder has recently called into question the separability of the Fort Union and the Laramie, in western North Dakota. Jour. of Geol., Vol. XII, p. 290.

[3] For criteria for distinguishing lacustrine and subaerial formations, see Davis, Science, N. S , Vol. VI, p. 619, 1897, and Proc. Am. Acad Arts and Sci., Vol. XXXV, p. 345, 1900.

[4] Little Belt Mountain, Mont., Folio, U. S. Geol Surv.

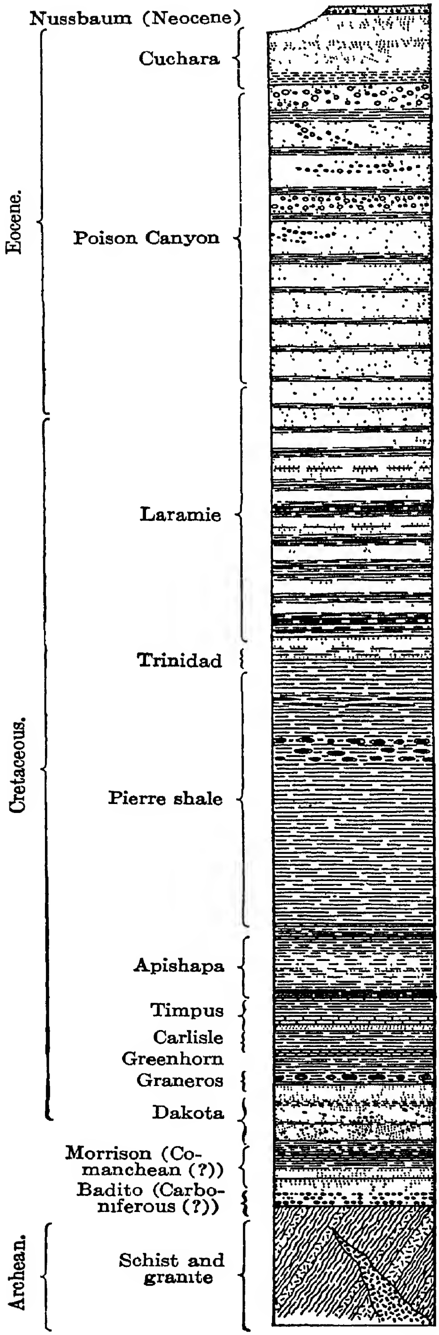


FIG. 422. — Column or section of the formations at the east foot of the Rocky Mountains, Colo. (Hills, U. S. Geol. Surv.)

begun by the time the Arapahoe and Livingston formations were deposited.

To the Early Eocene, the Telluride (or San Miguel[1]) and Poison Canyon[2] formations (Fig. 422) of Colorado are commonly assigned, although their equivalence to the Arapahoe of the Denver basin has been suggested. Locally, the Cretaceous had suffered as much as 7000 feet of erosion subsequent to the post-Laramie uplift before the deposition of the Telluride formation;[3] but great as this is, it does not exceed the post-Laramie erosion which is thought to have preceded the deposition of the Arapahoe formation (p. 158). The Telluride formation is conglomeratic, and has a maximum thickness of about 1000 feet, while the Poison Canyon formation, of sandstone and conglomerate, is said to attain a thickness of 2500 feet. The assignment of these formations to the Eocene is based on stratigraphy, for neither has yielded distinctive fossils. While both formations have been described as lacustrine, it is not clear that this is their origin. It is difficult indeed to conceive of lacustrine conditions which would permit the accumulation of such thick and extensive beds of conglomerate.

Another early Eocene formation (Puerco), nearly 1000 feet thick, is found in northeastern New Mexico and the adjacent part of Colorado. Its exact age has been the subject of much difference of opinion,[4] perhaps because the upper and lower parts of the formation have yielded fossils of different ages.

All the formations referred to the Fort Union stage of the Eocene, as well as the Arapahoe, Denver, Livingston, Ohio, and Ruby formations, are to be looked upon as representing the transition from the Mesozoic to the Cenozoic.

The early Eocene sites of deposition were finally shifted. In so far as the sedimentation had been in lakes, the basins may have been filled or warped out of existence, and in so far as the sedimentation had taken place subaërially, the deformative movements of the time, or the progress of the gradational work of the streams, or both,

[1] Purington, Telluride, Colo, Folio, U. S. Geol Surv. This formation formerly called San Miguel, is now known as the *Telluride* Bull. 182, U S. Geol. Surv., p. 36.

[2] Hills, Science, N. S., Vol. XV, p. 417, 1902, and Spanish Peaks and Walsenburg, Colo., Folio, U. S. Geol. Surv.

[3] 21st Ann. Rept. U. S. Geol. Surv., Pt. II, p. 99.

[4] Osborn, Bull. Am. Mus. Nat. Hist., Vol. VII, p. 1, 1895. Wortman, Sci., N. S., Vol. VII, p. 852, 1897, and Scott, Sci., N. S., Vol. II, p. 499, 1895.

may have been responsible for the shifting of the areas of deposition.

2. At a later stage of the period, as judged by the fossils, aggradation was in progress over much of Utah, western Colorado, and Wyoming. On the supposition that the sediments were all lacustrine, it was formerly suggested that a single great lake, perhaps formed by the spread and union of several earlier ones, may have reached from New Mexico on the south to the Wind River mountains on the north, during this stage of the period, covering a large part of western Colorado and eastern Utah, and having a length of about 500 miles, and a maximum width of 300. Even if the formations be partly subaërial, as their fossils and composition indicate, the preceding suggestion seems to emphasize the essential continuity of sedimentation over a great area.

The deposits of this time represent the *Wasatch* stage [1] of the Eocene (perhaps corresponding to the Chickasawan, p. 199). The beds of this stage have a maximum thickness of 4000 feet near the Wasatch range, and are now 6000 to 7000 feet above the sea. At about the same time, as indicated by the fossils, there was an area of sedimentation in the Bighorn basin in northwestern Wyoming. Some deformation of the Wasatch beds followed their deposition.[2]

The sites of other small areas of deposition believed to be referable to the Wasatch stage are known east of the mountians in southern Colorado [3] (Cuchara formation), and they doubtless occur at other points as well.

All Eocene formations of Wasatch age or older, are referred to the Lower Eocene.

3. The third recognized stage of the Eocene of the west is the *Bridger* [4] (perhaps corresponding to the Claibornian). During this stage, there were several known areas of sedimentation, lacustrine

[1] Here belong the Vermilion group of King, op. cit., the Coryphodon beds of Marsh, Am. Jour. Sci., Vol. 14, p. 354, 5th Ann. Rept. U. S. Geol. Surv., p. 252, and Mono. X, U. S. Geol. Surv., p. 6, and the Bitter Creek group of Powell Geol. of the Uinta Mountains, pp. 64 and 162.

[2] King, Geol Expl. of the 40th Parallel, Vol. I, p. 754.

[3] Walsenburg folio, U. S. Geol. Surv.

[4] The Green River group of Hayden, 3d Ann. Rept. U. S. Geol. Surv. of the Territories, 1869, p. 191, and Powell, Geol of the Uinta mountains, pp. 63 and 166; and the Wind River group of Hayden, Am. Nat., 1878, p. 831, and the Dinoceras beds of Marsh, are here included.

or subaërial, or both. In the several areas, the sedimentation was partly contemporaneous and partly successive. One area of deposition was in the Wind River basin, north of the mountains of that name. Later, deposition was in progress in the basin of the Green River in Wyoming, and also in the basin of the same river south of the Uintas. In these areas, beds of sediment, said to be locally as much as 2500 feet thick, were deposited.[1] The materials are chiefly clastic, though there is not a little calcareous matter in some places.[2] It may have been during this stage that the formation of volcanic tuff (San Juan, 2000 feet and less in thickness) of the Telluride region was made.[3] This formation is of interest as an index to the vigor of volcanic action in this region. At about the same time, the Huerfano formation, of Colorado, estimated to have a thickness of 3300 feet, was laid down. At the close of this stage there was some deformation in southern Colorado, where the beds already deposited were tilted. In some places (Sangre de Cristo range) mountain-making was in progress.[4]

4. The *Uinta* (perhaps Jacksonian) *stage*[5] followed the Bridger. Crustal movements, or the progress of gradation, or the effects of vulcanism, or all together, seem to have shifted the sites of sedimentation from the areas where the Bridger beds were deposited, to an area lying mostly south of the Uinta mountains, in southeastern Utah and southwestern Colorado. The area of the Uinta deposits occupied a part of the area covered by the Wasatch and Bridger formations, and where this was the case, the Wasatch, Bridger, and Uinta beds are found in superposition. The Uinta beds now have an altitude of 10,000 feet, though they may have been deposited at a much lower level.[6] At the close of this stage, the new-made deposits were tilted and somewhat deformed.[7]

Eocene deposits of lacustrine or subaërial origin are known at numer-

[1] King, op. cit.

[2] King, op. cit., p. 381.

[3] Purington, Telluride, Colo, folio, U. S. Geol. Surv.

[4] Hills, Walsenburg folio, U. S. Geol. Surv.

[5] Here belong the Diplacodon beds of Marsh and the Browns Park group of Powell; Geol. of the Uinta Mountains, pp. 63, 168, 208.

[6] It is possible that some of these beds should be referred to the Oligocene stage of the period.

[7] King, op. cit., p. 448.

ous other points in the western mountain region. In northern Oregon, there are late Eocene beds of terrestrial origin (Clarno formation) in the John Day basin, which was the site of aggradation during a large part of the Tertiary. The Clarno beds are chiefly of volcanic tuff.[1] Eocene beds of similar nature occur in western Oregon, central Washington, and northwestern Idaho.[2] In Washington, two thick, sedimentary formations (the Swauk, early Eocene, 3500–5000 feet, below, and the Roslyn, 3500 feet, above) of Eocene age and non-marine origin, are separated by 300–4000 feet of basalt (Fig. 423). The Swauk formation (conglomerate, arkose, sandstone, shale, etc.) is described as lacustrine, while the Roslyn contains much coal.[3] The Payette formation of Idaho, formerly classed as Miocene, is now referred to the Eocene.[4] It is said to have been accumulated in a lake formed by the damming of the upper basin of the Snake river, by the early lava-flows of the Columbia river region.[5] The Payette beds range in altitude from 4100 to 6900 feet. If they are all lacustrine, a large part of this range is due to later deformation.

Eocene beds of terrestrial or volcanic origin are imperfectly known at other points, as in the Yellowstone Park[6] (Pinyon conglomerate), in the Absaroka[7] region to the east, in Montana[8] (Sphinx conglomerate), in Arizona[9] (Whitetail conglomerate, fluviatile), where there were igneous eruptions and faulting before the end of the period, in Nevada[10] (Amyzon formation), in Utah (Manti, mainly shale),[11] and in southern California (Mojave formation, sandstone, clay, tuff, and lava-flows).

The sediments of the Eocene system of the western mountains are principally clastic, and there is not a little gravel and conglomerate. Associated with these common sorts of sediment, there is much pyro-

[1] Merriam, Jour. Geol., Vol. IX, p. 71, and Bull. Univ. of Cal., Vol. II, p. 285, and Knowlton, Bull. 204, U. S. Geol. Surv.

[2] Knowlton, op. cit., pp. 110–113.

[3] Smith, Geo. Otis, Mount Stuart, Wash , folio, U. S. Geol. Surv.

[4] Knowlton, op. cit., p. 110.

[5] Lindgren and Drake, Nampa and Silver City, Idaho, folios, U. S. Geol. Surv.

[6] Weed, Yellowstone Park folio, U. S. Geol. Surv.

[7] Hague, Absaroka, Wyo., folio, U. S. Geol. Surv.

[8] Peale, Three Forks, Mont., folio, U. S. Geol. Surv.

[9] Ransome, Globe and Bisbee folios, U. S. Geol. Surv.

[10] King, op. cit., p. 393; and Cope, Am. Nat., Vol. XIII, p. 332, 1879.

[11] Cope, Am. Nat., Vol. XIV, p. 303, and Vol. XXI, p. 454, 1887.

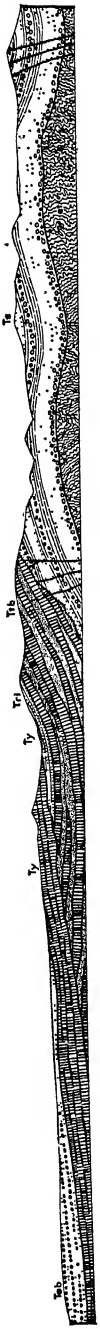


FIG. 423.—Section showing the structure of the Eocene in central Washington. *Ts* (Swauk formation) and *Trl* (Roslyn formation), Eocene; *Ttb*, pre-Rosyln Eocene basalt; *Ty*, Early Miocene basalt; *Teb* (Ellensburg formation), Miocene. (G. O. Smith, Mount Stuart, Wash. folio, U. S. Geol. Surv.)

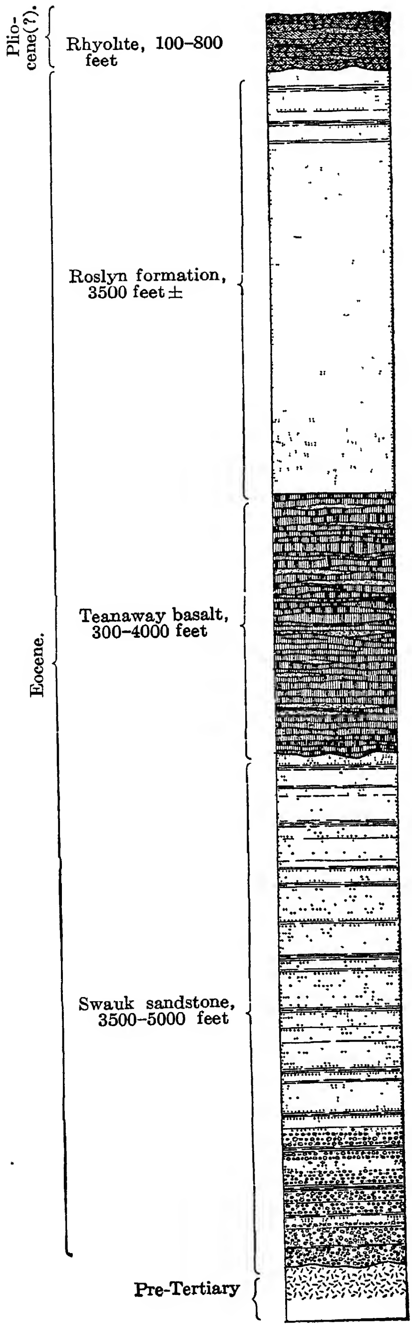


FIG. 424.—Section of the Eocene in the vicinity of Mt. Stuart in the central part of Washington. (G. O. Smith, U. S. Geol. Surv.)

clastic rock and some lava. The beds are for the most part but imperfectly indurated, and their erosion has locally given rise to the topography characteristic of "Bad Lands."

Subaërial formations of Eocene age have not been certainly identified far east of the Cordilleran region. It has recently been suggested, though with little probability, that certain preglacial gravels of Indiana may belong to this system.[1]

Igneous activity.—The period of igneous activity which was inaugurated with the close of the Cretaceous seems to have continued, at least intermittently, throughout the Eocene, for igneous rocks of Eocene age are found in California,[2] Oregon,[3] Washington,[4] Idaho,[5] Montana,[6] Wyoming,[7] and Colorado.[8] In some places, the exact age of the igneous rocks associated with Eocene sedimentary beds has not been determined, but volcanic ash and other forms of fragmental volcanic matter form a part of the Eocene system at so many points in the west, and so many lava sheets are associated with the sedimentary beds of the system, that there can be no doubt as to the widespread volcanic activity of the time. Igneous rocks of Eocene age are also known south of the United States in the Antillean and Central American regions.

General considerations.—Judged by the thickness of the beds in most places, the Eocene period would seem to have been of less duration than most of the periods which preceded. This, however, is not a safe criterion for the estimate of time, since it does not take into account either the discontinuity of sedimentation in any one place throughout the period, or the rate of sedimentation. Even on the basis of thickness, however, the showing of the system is by no means insignificant, as the formations of Puget Sound, Coos Bay, Ore., and southern California show. In the western interior, too, the thickness of the beds is often great, especially when it is remembered that

[1] Fuller and Clapp, Patoka, Ind.-Ill. folio, U. S. Geol. Surv.
[2] Hershey, Am. Geol., Vol. 29, p. 349.
[3] Diller, Roseburg, Ore., folio, U. S. Geol. Surv.
[4] Smith, G. O., Mount Stuart folio, U. S. Geol. Surv.
[5] Lindgren and Drake, Nampa and Silver City folios, U. S. Geol. Surv.
[6] Weed, Fort Benton and Little Belt Mountain folios, U. S. Geol. Surv.
[7] Hague, Absaroka folio, and Iddings, Yellowstone folio, U. S. Geol. Surv.
[8] Telluride, La Plata, Spanish Peaks, Walsenburg, and Anthracite and Crested Butte folios, U. S. Geol. Surv.

the thickness of the system should include the thicknesses of the beds deposited in the several successive areas of deposition. King estimated the maximum thickness of the Eocene near the 40th parallel at 10,000 feet.[1] Furthermore, any just estimate of the duration of the period must take account of the great erosion after the post-Laramie deformation, and before the recognized Eocene deposition began, in the places where the beds are now known, for it is to be remembered that the Eocene beds are generally unconformable on the Cretaceous. Thus in western Oregon, the Cretaceous formations had been largely removed, and the surface well advanced toward base-level after the post-Cretaceous deformation, before the incursion of the Eocene sea permitted marine sedimentation within the present land area. After Eocene sedimentation began, there was still time before the end of the period for the deposition of 10,000 feet (as sedimentary beds are measured) before the close of the period. We must not conclude therefore that the Eocene period was short, because the system is thin in many parts of the continent.

The conditions requisite for so great thicknesses of terrestrial sediment as occur in the Eocene of western North America are not easily conceived, if the thicknesses are really as great as they have been thought to be. If the region of sedimentation was in process of more or less continuous warping, the depressions deepening as the surrounding lands were elevated, or if troughs or basins of deposition were produced by faulting, the bottoms sinking while their surroundings rose, the conditions for thick sediments would be met. It has sometimes been urged that such formations as those of the Eocene of the west are too thick to be subaërial, but it is not apparent that it is more difficult to account for thick subaërial sediments, under the conditions indicated, than to account for thick lacustrine or even marine formations.

The relations of the Eocene beds accumulated in lakes or on the land are such as to indicate that both the attitude and the altitude of the surfaces in the western half of the continent were very different from those which now exist. The western part of the continent must have been, on the whole, much lower than now, and, locally and temporarily at least, without well-established drainage. The present

[1] King, op. cit., p. 541.

mountains were certainly not so high as now, though considerable elevations and great relief must have existed to furnish the abundant sediments.

Close of the Eocene in North America.—The closing stages of the Eocene were marked by crustal movements in the west, resulting in considerable changes in geography. Such movements had been in progress throughout the period, as has been indicated, but the changes at the close were on a larger scale. The deformative movements seem to have included faulting and folding, as well as general crustal warping. The results of these movements were the withdrawal of the sea from the lands which it had covered along the Pacific coast, and the development of new areas of high and low lands, and therefore a shifting of the areas of rapid degradation and aggradation. Among the deformations connected with the close of the Eocene were the renewed upbowing of the Klamath mountains,[1] the beginning of the development of the Coast range of Oregon,[2] and the notable deformation (folding) of the newly deposited sediments in central Washington,[3] and in the Santa Cruz mountains of California.[4] In and about the Basin region,[5] faulting, rather than warping and folding, seems to have been the prevalent phase of deformation, though the faulting at the close of the Eocene is not always separable from that of later times. In Colorado, deformation at the close of the Eocene is recorded at numerous points,[6] with the general result that degradation succeeded aggradation in some places, while the change was reversed in others. Faulting and warping also seem to have occurred in New Mexico and Arizona at about the same time, resulting in changes which stimulated erosion in those regions in the epoch which followed. These crustal movements seem to have been connected, in more than an accidental way, with an increase in the vigor of igneous activity, as shown by the extrusions of abundant igneous rock near the close of the period.

Outside the Cordilleran region there were lesser changes. Along the Atlantic and Gulf coasts the Miocene is in many places uncon-

[1] Diller, Bull. 196, U. S. Geol. Surv.

[2] Diller, Port Orford, Ore, folio, U. S. Geol. Surv.

[3] Smith (G O.), Mount Stuart, Wash, folio, U. S. Geol. Surv.

[4] Ashley, Jour. of Geol., Vol. III, p 434 et seq.

[5] Dutton, Mono II, U. S. Geol. Surv, and King, op. cit., p. 541.

[6] See Colorado folios of the U. S. Geol. Surv.

formable on the Eocene, and it was at the close of the Eocene (or perhaps during the Oligocene) that an island, now included in the peninsula of Florida, was formed. In the Carolinas, and in the western Gulf region, the conformity between the Eocene formations and those classed as Oligocene seems to preclude notable changes of geography along the coast in the southeastern part of the United States, at the close of the period.

Foreign.

Europe.—The Eocene beds of Europe may be grouped in three principal areas, viz.: (1) The London-Franco-Belgian basin, including the deposits of England, northern France, Belgium, etc.; (2) those of south Europe west of Russia, and (3) those of south Russia. This distribution, when compared with that of the late Cretaceous, shows that there was a wide-spread withdrawal of the sea from northwestern and central Europe at or near the close of the Cretaceous period. At this time Great Britain probably became connected with the continent, though considerable lakes, estuaries, and perhaps other areas of deposition remained over western Europe within the area from which the sea withdrew. Later, but still early in the Eocene, submergence of the land set in, allowing the sea to again overspread considerable areas from which it had been temporarily excluded. In western and central Europe the maximum submergence of the Eocene seems to have been accomplished by the middle of the period (Fig. 425). Toward its close, the epicontinental waters of the northwestern part of the continent were again restricted. It follows that in the earliest stages of the period, the epicontinental deposits in the northern and central parts of the continent were largely of fresh- and brackish-water origin; that those of a later stage were more generally marine; while those of still later stages were largely non-marine. The geographic changes in southern and eastern Europe at the close of the Cretaceous period seem to have been less considerable.

The interval of rather general emergence in northwestern Europe, following the close of the Cretaceous, must have been a somewhat protracted one, for the next marine deposits (mid-Eocene) of this region carry a fauna notably different from that of the Cretaceous beds below. During this interval, the Mesozoic types of life (except the lower forms) gave place to modern ones. In many places, too,

the Cretaceous beds were deeply eroded before the deposition of the overlying Eocene. The break between the Cretaceous and the Eocene was long regarded as one of the great breaks in the geological record, but the hiatus is partially and imperfectly bridged by the estuarine, lacustrine, and other deposits of the Early Eocene. It is not to be

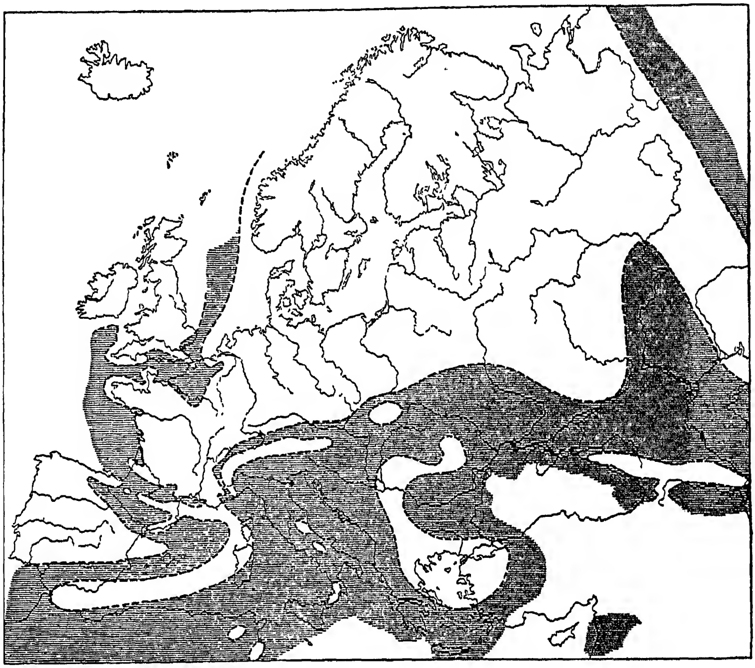


Fig. 425.—Sketch-map of Europe, during the Eocene, Lutetian stage. The shaded portions represent areas of deposition. (After De Lapparent.)

lost sight of that the one period merged insensibly into the next, even though the strata which recorded the transition may not be found in every region. In southern Europe, the separation of Cretaceous and Eocene is much less sharp, showing that the notable geographic changes of the western region did not affect the southern and south-eastern parts of the continent, or at least not to the same extent.

To the early Eocene lakes, estuaries, and other sites of deposition, in western Europe, and later to the sea which covered a part of the same area, considerable streams flowed from the surrounding lands. Into the arm of the sea which covered parts of England, France, and

Belgium before the close of the Lower Eocene, the drainage from eastern Britain and Norway[1] brought plants (palms) and animals (crocodiles, alligators, etc.) now characteristic of tropical latitudes. The Tertiary of the Paris basin especially is famous for its wealth of fossils. The Lower Eocene of this basin is largely of non-marine origin, and contains some coal; the Middle is marine, and includes both nummulitic limestone and glauconitic beds; while the Upper is marine below, but non-marine above.

The Eocene of central and western Europe is mostly of clastic origin, and the beds are still unindurated. The aggregate thickness of the system in England is about 1700 feet.

In southern Europe, the Eocene sea spread much beyond the borders of the present Mediterranean, covering much of the southern part of Europe. It also overspread the northern part of Africa and part of southeastern Asia. Connecting freely with the Indian Ocean, it cut off the southern peninsulas of Asia from the continent to the north. In western Europe, an arm of the Mediterranean sea swung around the north side of the Alps and Carpathians, and extended thence eastward, connecting in that direction with the water which covered much of southern Europe. A narrow sound east of the Urals probably connected the Arctic ocean with this expanded Eocene Mediterranean. Out of this extended sea rose many islands, some of which corresponded in position to the Alps, Carpathians, Apennines, and Pyrenees.

On the bottom of this great body of water, which should perhaps be thought of as a part of the ocean rather than as a Mediterranean sea, limestone was deposited on an extensive scale. Much of it is made up almost wholly of the shells of nummulites, a genus of foraminifera, and is known as *Nummulitic limestone*. This limestone is known in the Pyrenees, the Alps, the Apennines, the Carpathians, in Greece and Turkey, at various points in northern Africa, in Asia Minor, Persia, Beloochistan, India, Farther India, China, Japan, Java, Sumatra, and the Phillipines. It is, in short, found from one side of the Old World to the other. While the limestone is sometimes made up almost wholly of foraminiferal shells, it often contains other types of fossils in abundance. The rock is often firm and even crystalline. In this respect the Eocene of southern Europe is in sharp contrast with the unindurated, new-

[1] James Geikie, Outlines of Geology.

looking beds of the Paris basin. Since it is often thick, as well as widespread (it locally attains a thickness of several thousand feet), the sea must have swarmed with foraminifera. Hardly anywhere else in the rocks of the whole earth are there indications of such great numbers of organisms of one type. The Hippurite limestone of the Cretaceous, and the Fusulina limestone of the Carboniferous, are perhaps most nearly comparable. Fossil nummulites are also found in the sandstones, and even in the iron ores of the period.

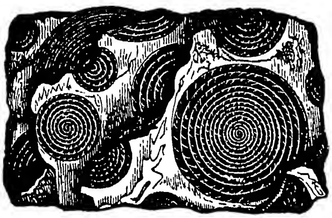


Fig. 426.—A bit of nummulitic limestone.

In the northern Alps and Carpathians, there is a series of clastic beds known as the Flysch. The lower portion of the series is believed to be Cretaceous, but in Bavaria the upper portion is associated with nummulitic limestone, and is therefore thought to be Eocene. The peculiarity of this formation is the occurrence within it of gigantic bowlders, some of which are said to have a diameter of 100 feet. They occur singly or in groups, and are sometimes embedded in clay, though more commonly they are a constituent of conglomerate. Some of the bowlders are foreign to the adjacent mountains, and have been thought to suggest the existence of glaciers. The paucity of fossils is in harmony with this suggestion, without proving its truth. If this inference be correct, it would seem that there must have been high mountains in central Europe, for a low temperature does not appear to have affected any considerable area of the sea. From high mountains, glaciers might have descended to low levels, as in New Zealand to-day, where between latitude 43° and 44° S., glaciers descend to within 500 feet of the sea-level, and deposit their moraines in a region of tree ferns and palms.[1]

Against this interpretation much may be said. At any rate the fossils of the period in the surrounding regions denote a climate too warm to allow the hypothesis to be accepted, except on the basis of irrefutable evidence. Similar problems are presented by certain formations of other periods. In the North Tyrol, the Eocene contains coal. Igneous rocks of Eocene age are common in Europe as in America.

Some idea of the deformative movements which have taken place since

[1] James Geikie. Outlines of Geology.

the Eocene may be gained from the fact that the nummulitic limestone occurs at elevations of more than 10,000 feet in the Alps, up to 16,000 feet in the Himalayas, and up to 20,000 feet in Tibet. It is possible that the Himalayas and Alps had begun their growth before the Eocene, but the above figures represent their respective minimum post-Eocene uplifts. The Pyrenees and Carpathians were likewise low in the Eocene period, their principal elevation being of later date. The Caucasus, Thian Shan, and other high mountains of Eurasia are also in large measure of post-Eocene growth. In the Old World, therefore, as well as in the new, the greater relief features of the present time were still undeveloped in the Eocene period.

Other continents.—In Africa, marine Eocene is known along the northern coast, on the west coast, and in Soudan [1] (Sokoto). The fossils of Sokoto indicate a connection between the mid-Eocene Indian ocean, and the waters which overspread Soudan, by way of Egypt.[2] In some parts of Egypt, the Eocene is notably unconformable on the Cretaceous.[3] Eocene beds are known in South Australia, New Zealand and Tasmania, though not generally sharply differentiated from the later Tertiary. At the head of the Great Australian bight, there is a thick bed, 250 feet or more, of Eocene chalk. In New Zealand the Eocene is said to grade into the Cretaceous below without break. Eocene beds are also known on the island of Luzon,[4] in Java, in Borneo,[5] and in Japan.[6]

Of the Eocene of South America little can be said. The Tertiary formations of this continent have not been closely correlated with those of other regions. There is marine Eocene along some parts of the western coast, in Patagonia [7] (Magellanian series), where the beds are usually unconformable on the Cretaceous, probably in Argentina, and along at least a part of the coast of Brazil.[8] Eocene beds of non-

[1] Lelean, Geol. Mag., 1904, p. 290.

[2] De Lapparent, La Geographie, Vol. XI, p. 1.

[3] Beadnell, Geol. Mag, 1901, p. 23.

[4] Becker, 21st Ann. Rept., U. S. Geol. Surv., Pt. III, p. 552–6.

[5] Becker, 21st Ann. Rept, U. S. Geol. Surv., Pt. III.

[6] Geol. of Japan, Imp. Geol. Surv. of Japan, p 77.

[7] Hatcher, Sedimentary Rocks of Southern Patagonia. Am. Jour. Sci., Vol. IX, 1900, pp. 97–99; also Geology of Southern Patagonia, idem, Vol. IV, 1897, pp. 334–337.

[8] Branner, Bull. Geol. Soc. Am., Vol. 13, Stone Reefs of Brazil Mus. of Comp. Zool., Bull. 44, pp. 27–53.

marine origin also occur in Patagonia.[1] Both marine and non-marine Eocene may be much more widely distributed.

Eocene beds, not always distinctly separable from the Oligocene, are extensively developed in the West Indies, where limestone is the dominant type of rock. In Cuba,[2] the Eocene beds (together with the Oligocene) occupy the surface of about half the island. In Jamaica[3] the Eocene is distinct from the Oligocene. Eocene beds grading up into Oligocene without interruption are present on the island of Trinidad, and are extensively developed on the eastern side of Panama,[4] and in Central America. They are partly clastic, and partly limestone. Material derived from igneous rocks enters largely into their composition, and extensive extrusions of basic rocks occurred in this region during the period. Some idea of the changes of later times may be gained from the fact that the Early Tertiary formations of the Caribbean region occur up to elevations of 5000 feet on the mainland, and up to elevations of 10,500 feet in Hayti.[5] The date of the principal deformation was later than the Eocene.

It was formerly thought that the Atlantic and Pacific oceans connected freely across Panama during the early Tertiary, but the work of Hill renders it doubtful whether there were more than shallow and restricted connections in the Eocene, and whether there were connections of any sort at a later time.

General geography of the Eocene.—From what has been said it is clear that Eocene geography was very different from that of the present time, and differences still greater than those already indicated are conjectured. North America was perhaps connected with Asia on the west, via Alaska, and with Europe on the east, via Greenland and Iceland.[6] Land seems to have failed of making a circuit in the high latitudes of the north only by the strait or sound east of the Urals.

In the southern hemisphere, it has been surmised that Antarctica was greatly extended, connecting with South America, Australia, and

[1] Ameghino, L'age des Formations Sedimentaires de Patagonia, Anales de la Sociedad Crentipica Argentina, 1903.

[2] Hill, Cuba and Porto Rico.

[3] Hill, Geology and Physical Geography of Jamaica, 1899.

[4] Hill, Geological History of the Isthmus of Panama and Portions of Costa Rica. Bull Mus. of Comp Zool., Cambridge, 1898.

[5] Idem.

[6] Neumayr, Erdegeschichte Bd. II.

possibly with Africa. The basis for these conjectures is found in the distribution of life at that time, as shown by fossils. It has also been thought that Africa and South America were connected across the Pacific from some earlier time until after the beginning of the Eocene.[1]

If these conjectured extensions of land were real, it will be seen that the division of land and water in the northern and southern hemispheres was far less unequal than now, and that the land was massed in high latitudes to a greater extent than at present, while tropical seas were much more extensive. If extensive polar lands were the cause of glacial periods, it would seem that the geographic conditions during the Eocene were favorable in the extreme, if the relations sketched above were the real ones. In spite of this, the climate of the period seems to have been genial, and less markedly zonal than now.

Close of the Eocene.—During the later part of this period, and at its close, there were some notable deformations in Europe. The initiation of the Pyrenees, and of some of the mountains farther east, is assigned to this time, and the distribution of the later formations, when compared with the distribution of the Eocene, shows that changes of a less pronounced type were in progress elsewhere.

The Eocene Life.

I. *The Transition from the Mesozoic to the New Era.*

Four salient features marked the transition of life from the Mesozoic to the Cenozoic era: (1) In marine life, nearly or quite all Cretaceous species were replaced by new ones; (2) in the terrestrial plant life so many species lived across the transition interval as to render the placing of the dividing plane between the Mesozoic and Cenozoic in western America one of the most mooted of classificatory questions; (3) the great saurians, from the dinosaurs of the land to the mosasaurs of the sea, disappeared, and most other reptiles showed profound changes, constituting a revolution in the animals of the land corresponding to that of the sea, but contrasted with the continuity in the terrestrial vegetation; and (4) placental mammals appeared in force and promptly took a dominant position. The combination is unique, in that, while half the land life joined with the sea life in undergoing a profound transformation, the other half of the land life did not notably participate

[1] Neumayr, Erdgeschichte Bd. II.

in the revolution. In explanation of profound transformations of epicontinental marine life, appeal has been made repeatedly to the withdrawal of the sea, to the extension of the land, and to climatic changes incident to deformative movements, and this appeal may now be made so far as the change in the sea life is concerned; but the contrasted phenomena on the land raises a new and unique question. The withdrawal of the sea from its wide extension in Cretaceous times seems in this case peculiarly well fitted to explain the transition in the epicontinental sea life, because of the great differences in the areas of shallow water in the two periods. It is worthy of note in passing, that the distribution of the harbors of refuge and other transition tracts of this transformation had many points of analogy with those of previous transformations, the Mediterranean region being again conspicuous in this function. Such repeated service is a most significant illustration, not simply of the persistency of continents, but of special continental configurations.

The increase of the land area and the establishment of new land connections attendant on the post-Cretaceous withdrawal of the sea might well have caused the vegetation to spread and flourish, if the climate remained congenial; but why did not the animal life respond in like manner? The record shows that plant life suffered little, although plants are on the whole more responsive to climatic and topographic influences than animals; why, then, did the saurians suffer so much?

Closely correlated with this problem is the question, whence came the placentals? Had their apparition anything to do with the extinction of the saurians and the repression of the rest of the reptile horde? The origin of the placentals is one of the great outstanding problems of paleontology. It is yet an open question whether the placental mammals of North America and Eurasia arose from non-placental mammals that had been natives of these provinces in the Jurassic and Cretaceous periods, or whether they were immigrants from some other region. No satisfactory evidence of a transition from non-placental to placental mammals in Eurasia or North America has yet been produced, but the imperfection of the record may be appealed to. The relative suddenness and overwhelming power of the placental irruption suggest invasion from some other quarter in which the earlier evolution of the placentals had been in progress for a long time previously; whether from marsupial or from independent stock, we need not here inquire. The

deformative movement which closed the Cretaceous period and inaugurated the Eocene quite certainly made many new land connections, and furnished the conditions for a migratory invasion, if, in any of the previous areas, a mammalian stock of the requisite potentialities was awaiting the opportunity.

Some of the hypotheses of the place of origin of the placentals look to relatively isolated areas within the northern hemisphere. Some special fitness may be assigned to one of these, the old lands of northeastern North America, the area in which the angiosperms probably originated. During the larger part of the Cretaceous period this was isolated from the western portion of the continent by the great "mediterranean" sea of the Great plains region. In such intervals as there may have been between the actual sea occupancy of this tract, it was the site of extensive lowlands interrupted by lakes, swamps, and plexuses of streams, more inviting to reptiles than to upland mammals. Unfortunately, the Cretaceous record of the old northeastern lands is almost entirely wanting. We have already noted that the deployment of the angiosperms in that region invited a biological revolution which did not seem to be registered during the Cretaceous. The hypothesis that the placentals were evolving there during the Cretaceous responds to this obvious fitness of things. A dispersion from this area, when the deformative movement at the close of the Cretaceous made the requisite land connections, is not inconsistent with the fact that the earliest American deployment of placentals is recorded in the Puerco beds of Colorado and New Mexico, and the earliest European in the Cernaysian formation of France, and that these were followed by the more pronounced and cosmopolitan dispersion which took place in the Wasatch epoch, when "the correspondence between the mammals of Europe and North America was never closer."[1]

As an alternative view, an originating tract for the placental mammals has been postulated in the high northern latitudes, partly on the theoretical presumption that the oncoming of cool climates would earliest affect that region, and partly because not a few of the migratory paths of the Tertiary mammals seem to have trended southward. As, however, the land connections between Eurasia and North America seem to have been wholly in high latitudes, it is difficult to distinguish between what might have been migrants from a neighboring continent,

[1] Scott, Introduction to Geology, p. 505.

and what might have originated in the high-latitude area, since both of these would necessarily move southward in invading the continental regions where their relics are chiefly found.

All hypotheses that postulate an origin in Eurasia or North America are somewhat, though not absolutely, dependent on the hypothesis that the placentals descended from the non-placentals of these regions. Some paleontologists have, however, entertained the view that the placental and non-placental branches diverged from a common stock at an early stage, probably far back in Mesozoic times. This view lends whatever strength it may have to the hypothesis that the placentals arose in some region whose record has not yet been carefully studied, because the transition forms do not appear, at least in sharp definition, in the European or the American Mesozoic record.

Of such uninvestigated regions, Africa presents the most favorable antecedents for placental origination. Australia is excluded, because placentals do not seem to have ever lived there, until recently introduced, and South America also, for its placentals seem to be provincial and limited in type-range, as though they were the offspring of a branch that became isolated early and developed by itself. The common parents of all placentals should be rather markedly comprehensive. South America seems also to have been in migratory relations with Australia after the appearance in other lands of the primitive placentals, for carnivorous marsupials of comparatively recent Australian types lived there. In Africa, on the other hand, the placentals are comprehensive in type-range, are highly developed, and widely deployed, and have a remote mammalian ancestry, with living relics of primitive stock. It will be recalled that in the Permo-Triassic times, when the amphibians were deploying into the ancestral branches from which all reptiles, birds, and mammals have probably descended, the Karoo beds of South Africa displayed an extraordinary vertebrate fauna in which the mammalian strain of reptiles was a conspicuous feature. More definite foreshadowings of the coming mammalian race were shown there than anywhere else, notwithstanding the relative scantiness of our knowledge of the "dark continent." At present, Africa is almost the sole home of the least modified survivor of one of the great branches of the primitive placentals, the *Condylarthra*, in the form of the hyrax, the coney of the Bible, which has crept out into Syria, but is otherwise confined to Africa, where one species is found in the northeast, one on

the west coast, and two in South Africa. It has been demonstrated recently that the proboscideans originated in Africa, and did not emigrate until about the Middle Tertiary. These and other considerations that must here be passed by give some plausibility to the view that the placentals had their early evolution in the dark continent during Mesozoic times, and emerged thence and overran the other continents at the opening of the Cenozoic era. Some part of this plausibility doubtless lies in our ignorance of what took place in "darkest Africa" in this era, a plausibility that is not without its dangers.

All these suggestions rest on a slender basis of evidence and have their chief value in giving interest and suggestiveness to the remarkable facts connected with the disappearance of the great Mesozoic dynasty of reptiles, and the apparition of the placentals.

The rise of placentals was an assignable agency for the downfall of the reptiles, though it cannot be affirmed to have been the actual cause. The placental habit of bringing forth relatively mature offspring, and of nourishing and protecting them, was in itself an immense advantage to the race. The eggs of the reptiles were wholly passive subjects of prey, and during the immature stages after hatching, the young were probably without any intimate relations to the parent for either nourishment or defense. To this great advantage of the placentals at the beginning of life, were added superior agility, as a rule, and higher brain power. It is not surprising, therefore, that the placental invasion resulted in the clumsy, affectionless, small-brained reptiles being driven either into extinction, or into the sedges and rushes, the swamps and lagoons, the coverts of the jungles, the crevices of the rocks, and the various by-ways which the placentals cared least to frequent, and that they have been kept there to this day.

In a way not implied above, the angiospermous flora may have been a factor in the placental dispersion through the fact that it is the staple source of food of the mammals. It may have been the dispersion of this flora from its originating tract, until it came into contact with the primitive placentals in their originating tract, that caused the rapid spread and evolution of the latter, on a principle often illustrated in human experience, of which perhaps there is no better example than the recent spread of the Colorado potato-beetle when touched in its native region by the western spread of the potato-plant, through the agency of the chief of placentals. This would shift the importance of

the land connections from migratory facilities for the animals, to their function in plant distribution. Not only because of this possible function of the vegetation, but because of its incontestible agency in directing the evolution of the mammals, we turn to it first in sketching the life of the Eocene.

The Eocene Vegetation.

In plant history, the Eocene was not eocene, the dawn of the recent, for the great change from the medieval to the modern, in its main essentials, had taken place in the Early Cretaceous. The Eocene was not even the period of any radical innovation. There was, however, much progress toward the specific forms that now live, and toward the more recent adaptations to climate, soil, and topography, and toward those relationships of plant to plant that have worked out into the present plant societies. In Cretaceous times there was much mixture of forms that have since become dissociated, and the mixed state continued in large measure through the Eocene. On account of this mixture, climatic inferences have to be drawn with some caution. Where palms and poplars grow together, it is not quite clear whether the present environment of the palms or that of the poplars is implied. Very likely conditions not quite like either of these are implied, but rather climates of a less differentiated or less diversified nature.

The temperate (?) flora of the earliest Eocene.—The plants of the Heersian system (Heers, Belgium), the earliest known Tertiary flora of Europe, interpreted from the present adaptations of the species, imply a temperate climate. Most abundant among them were oaks like those of the present elevated districts of warm temperate zones. With these were associated willows, chestnuts, laurels, ivies, aralias, and other plants, making up an interesting group which Saporta likens to that of southern Japan, and Prestwich regards as very different in significance from the tropical palms, tree-ferns, and associated plants of a later stage of the Eocene. An assemblage of similar temperate facies occurs in the Paris basin, and in the Lower Eocene of England. The American flora of this stage yet awaits determination.

The tropical (?) flora of the Middle Eocene.—In a later stage of the Lower Eocene (London clay), a rich assemblage of trees grew in England, embracing palms, figs, cinnamon, and many others which, interpreted by present ranges, imply a somewhat tropical climate. In the Middle

Eocene, the prolific Alum Bay (England) plant-beds record a flora "the most tropical in general aspect which has yet been studied in the northern hemisphere,"[1] while the abundant Bournemouth (England) flora, perhaps a little later "suggests a comparison of its climate and forests with those of the Malay Archipelago and tropical America." It was an epoch of palms in mid-latitudes. The Mid-Eocene series of America in temperate latitudes contains palms and bananas mingled with many similar mild temperate trees, implying sub-tropical or warm-temperate conditions.

Some of the leading plants of the middle and late Eocene of Europe and America were allied to types that now prevail in India and Australia, and hence the Eocene flora is often said to have had an Australian facies, an expression liable to misinterpretation. The facts do not imply that these types originated in Australia, or were even necessarily living there in Eocene times, but merely that the descendants of the Eocene plants now live there. It is the more needful to observe this, because the nearest living relatives of another part of the Eocene plants of America and Europe are now found in portions of tropical Africa and America, while those of still another part are found in temperate and even boreal latitudes in America. An adaptive differentiation seems to have taken place since, attended by a dispersal of the differentiated groups to different climatic zones. Probably the true view is that the mixed or undifferentiated flora of the Cretaceous and Eocene, when it came to be subjected later to severe climatic and other crucial conditions, became modified into adaptive groups, some of which came to be restricted to the tropical regions and are now known as tropical plants, others to the temperate, and still others to boreal regions, acquiring corresponding designations. These later meanings can be carried back to the ancestral plants only at a certain risk of error. It is doubtless wise to make some discount in the direction of intermediate conditions, the conditions from which all probably diverged.

The flora as food-supply.—The presence of the angiospermous flora in the northern continents at the time of the appearance of the placental mammals, without doubt had far-reaching biological consequences. The rapid development of the ancestral herbivores, rodents, sloths, and lemurs, was doubtless, in some large measure, controlled by adaptation

[1] Geikie, Text-book of Geology, 3d ed., p. 974.

to the different edible portions of the angiosperms. Grasses had appeared in the Cretaceous and were present during this period. Although the evidence is too scanty for positive affirmation, it is not improbable that the shifting lakes and meandering rivers of the Eocene gave rise to sedgy meadows and grassy plains, and through these aided in the evolution of the grass-feeding herbivores and, as a secondary consequence, led on to the evolution of the carnivores that preyed upon them. It can scarcely be doubted that the sweet foliage of the angiosperms proved a more congenial food for mammals than the needles of the conifers, or the coriaceous and bitter foliage of the pteridophytes.

The Land Animals.[1]

The undifferentiated nature of the early Eocene placentals.—It is scarcely possible to carry our familiar conceptions of the mammalian orders back to the Eocene prototypes, without importing distinctions which did not then exist except as potentialities. The earliest Eocene mammals were much more primitive and obscurely differentiated than even those of the Middle Eocene, and this rapid backward convergence

[1] For the more important literature on the American Tertiary Mammalia, see the numerous papers of Cope, Marsh, Osborn, Scott, Wortman, Matthew, and others, particularly; Marsh: Introduction and Succession of Vertebrate Life in America, Proc. A. A. A. S., Vol. XXVI, 1878, p. 211. The Origin of Mammals, Am. Jour. Sci. Vol. VI, 1898, pp. 406–409, also Geol. Mag., Vol. VI, 1899, pp. 13–16. Cope: Vertebrata of Tertiary Formations of the West, U. S. Geol. Surv., Vol. III, 1884. Osborn: The Rise of Mammalia in North America, Am. Jour. Sci., Vol. XLVI, 1893, pp. 379–392, and 448–466; the Evolution of the Teeth of Mammalia, Trans. N. Y. Acad. Sci., Vol. XII, 1894, p. 187; the Origin of Mammalia, Rept. Brit. A. A. S., 1897, pp. 686–687; also Am. Nat., Vols. XXXII and XXXIV, 1900, pp. 943–947, and Am. Jour. Sci., Vol. VII, pp. 92–96, 1899, and many other papers. Scott, On the Osteology of Mesohippus and Leptomeryx, with observations on the modes and factors of evolution in the Mammalia, Am. Geol., Vol. IX, 1892, p. 428; Osteology and Relations of Protoceras, Jour. Morph., 1895, pp. 303–374. Wortman: North American Origin of the Edentates, Science, Vol. IV, 1896, pp. 865–866; the Ganodonta and their Relations to the Edentates, Bull. Am. Mus. Nat. Hist., Vol. IX, 1897, pp. 59–100; the Extinct Camelidæ of North America, Bull. Am. Mus. Nat. Hist., Vol. X, 1898, pp. 93–142. Matthew (W. D), A Provisional Classification of the Fresh-water Tertiary of the West, Bull. Am. Mus. Nat. Hist., Vol. XII, 1900, pp. 19–75; Ancestry of Certain Canidæ, Viverridæ, and Procyonidæ. Adams (G. I.): The Extinct Felidæ of North America, Am. Jour. Sci., Vol. I, 1896, pp. 419–444, and Vol. IV, 1897, pp. 145–149.

seems to point to some set of conditions which caused an exceptionally rapid deployment of the great class at this stage, whatever their previous history had been. The coming into a new domain of rich and varied conditions, whether by immigration or indigenous development, may be safely included among these conditions.

The very earliest Eocene placentals, so far as they can be interpreted from the remains in the basal Eocene (Puerco beds of America and Cernaysian of France), constituted an assemblage of groups quite vaguely differentiated, in which the present orders were rather foreshadowed than distinctly expressed. The present great groups of herbivores were foreshadowed by the *Condylarthra*, and the carnivores, by the *Creodonta*, but these were not sharply distinguished, both classes being five-toed plantigrades, the ends of whose phalanges were armed with horny coverings that were neither quite hoofs nor claws. Thus the first stages of the now pronounced division into the ungulates and the unguiculates were only obscurely indicated. So obscure are the relationships of the ancestral edentates, the *Ganodonta*, that they have only been recognized recently through the critical studies of Wortman and Osborn. The insectivores were not more definitely characterized, and Eocene genera were referred to the order *Insectivora* and later withdrawn by the early paleontologists, because of their uncertain limitations and imperfect differentiation. The definition of the ancestral lemuroids was equally imperfect. All these orders seem, however, to have been represented in this obscure fashion. The rodents have not been recognized in the Puerco beds, though present in the Wasatch.

But so rapid was the early evolution that before the close of the Eocene, the *Herbivora* (*Ungulata*), *Carnivora*, *Edentata*, *Insectivora*, *Rodentia*, *Quadrumana*, *Cetacea*, and *Sirenia*, and probably the *Cheiroptera* were distinctly defined. Progress was even made in the evolution of some of the suborders and families. It seems to have been a most remarkable instance of rapid evolution. None of the present *genera*, however, are known as early as the Eocene. When it is recalled that the name Eocene was founded on the presence of some *species* of living invertebrates, the great difference between the stage of evolution of the invertebrates and of the placentals may be realized.

From this general view we may turn to some of the salient facts relative to the evolution of the several orders.

The main herbivorous line.—While the condylarths and creodonts were structurally near one another at the opening of the period, it was not long before a clear distinction arose between their respective derivatives, the hoofed herbivores (*ungulata*) and the clawed carnivores (*unguiculata*). The condylarths were small generalized forms with five toes and forty-four teeth, not yet developed into the true herbivorous type, but displaying differentiation in that direction. The accompanying figure shows the general features of the skeleton of one of the best-

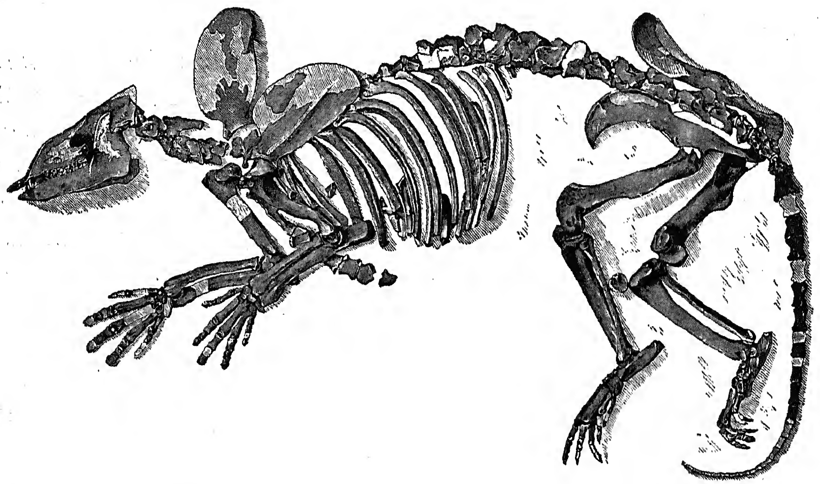


FIG. 427.—A primitive ungulate or condylarth from the second Eocene epoch (Wasatch) *Phenacodus primævus* Cope, about $\frac{1}{12}$ natural size (about the size of a tapir), from Big Horn basin, Wyoming. (After Cope.)

known genera (*Phenacodus*). Without radical change, the condylarths have lived on till the present time, but a branch seems to have diverged early, and to have deployed rapidly into the ungulates. This branch seems to have consisted of small five-toed forms adapted to forests and marshes where succulent vegetation afforded an easy sustenance. In the course of the period many of them became gradually fitted for life on the grassy plains. To this end, hard hoofs and powerful grinding teeth, capable of masticating coarse, dry herbage, were developed. The canine teeth gradually disappeared, and the molar and pre-molar teeth assumed flat, corrugated crowns seated on well-developed roots. The frontal teeth were variously adapted to cropping vegetation. In the foot there was a progressive abandonment of the flat heavy palmate

form, and the assumption of the light springy digitate habit, doubtless through the need of a quick start and a swift flight to escape the carnivores that were also abandoning the palmate form for the digitate. There was thus a sharp competition for increased speed, on the one hand to escape, and on the other to overtake, and on both sides there was a rising up on the toes with an increase of length of limb and a gain in elasticity. The evolution of the hoofs and of the grinding teeth have been thought to be intimately associated with an increased prevalence of grassy plains. As we have seen, the grasses were present in some abundance as early as the later Cretaceous[1] at least, and they had by this time been given ample opportunity to spread widely, and to fasten upon suitable ground and hold it with that remarkable virility and tenacity which is characteristic of the grasses, and which has made them so important a factor in modern food supplies. The firm turf which the grasses give is quite in contrast with the soft soil of the forests and ungrassed marshes. Because grasses are also much associated with dry and even semiarid grounds, dessication intensifies the firmness of the bottom, and gives additional occasion for the hoof. The tenacious fiber, the siliceous stiffening, and the dryness of the grasses at certain seasons, doubtless gave occasion for effective cropping incisors and grinding molars. The foliage of the angiosperms, which was more available for fodder than the needles and spines of the previous gymnosperms and pteridophytes, gave occasion for similar cropping and grinding teeth, and lent their influence to the transition, but served to retain in the forests a notable section of the evolving order.

Back of these influences lay the physical conditions that promoted them. In the western American region, where the evolution is best known, the great lakes and meandering rivers were characteristically undergoing shiftings. If these followed the method of like modern agents, they left behind them, as they shrank or shifted, a border of grassy or sedgy ground which, on fuller drainage, often became prairie, though this is not the sole explanation of prairies. Such changes were peculiarly suited to the evolution of herbivorous prairie life, and this in turn must have invited its appropriate contingent of predaceous animals. If these considerations be valid, the prime factors in the evolution of the ungulates were (1) an undifferentiated plastic animal group susceptible of

[1] Dawson, Plant Life, p. 195.

modification (a branch of the primitive *Condylarthra* in particular); (2) a plant group susceptible of becoming advantageous food for the new type, notably the grasses and subordinately the fodder-furnishing angiosperms; and (3) the shrinkage and shifting of lakes, marshes, and lodgment plains, and the drying up of the plains of the continent, resulting in prairies whose open field and hard turf invited the development of foot and limb modification in the interest of the greatest speed. The era of simple bulk and heavy armor had largely passed, and an era of agility, dexterity, and of light but effective weapons had begun. No small factor in this progress was the increase in intelligence disclosed by the larger brains. Intelligence henceforth proved an advantageous substitute for mass and mere brute strength. Corresponding with the lighter and more agile structure there was the development of smaller, simpler, but more effective weapons of attack and defense. Size nevertheless continued to be a factor of importance, and some species in almost every suborder grew in bulk until they reached and passed the point of mass-advantage, and thereafter declined.

Side branches that became extinct.—In the course of the early evolution some notable forms appeared, and a little later, became extinct. Of these the *Amblypoda* (blunt feet) took precedence for a time. They were a rather low type with diminutive, smooth brains, heavy bodies, stocky limbs ending in stumpy five-toed feet, with a partly digitate habit. They reached elephantine size; indeed they were much such a development of massiveness and clumsiness on the mammalian stem, as the dinosaurs had been on the reptilian stem, but the times did not equally favor their dominance and perpetuity. The most prominent offshoot from the *Amblypoda* in the Lower Eocene was the *Coryphodon* (Fig. 428). Near the middle of the period (Bridger epoch) the remarkable *Dinoceras* (terrible horn) appeared, followed later in the epoch by *Tinoceras*, with which the line of the *Amblypoda* seems to have become extinct. The *Dinocerata* (Fig. 429) were grotesque monsters whose skulls were armed with three pairs of protuberances perhaps horn cores, and a pair of enormous canine teeth or tusks projecting below, at least in the male, an extravagant attempt at armature on both upper and nether sides, but with meager results, if the short history of their endurance is a true index. Their brains were smooth and singularly small for such ponderous bodies. All mammalian brains of the time were diminutive and simple, compared with later forms (see Fig. 430), but

in the *Dinoceras*, brute-mass and low brain-power seem to have reached their mammalian climax, much as they had reached an earlier climax in the monster reptiles. Nearly all dominant forms thereafter showed

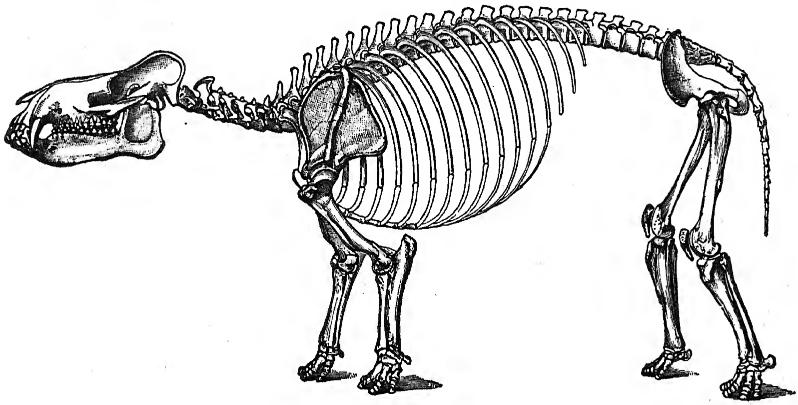


FIG. 428.—One of the *Amblypoda* of the Lower Eocene (Wasatch) *Coryphodon hamatus*, restoration of skeleton by Marsh. About $\frac{1}{18}$ natural size. For skull and brain see Fig. 430*a*. From Wyoming. (After Marsh.)

notable increase in the size and complexity of the brain, and from this time on there was a gradual transition from the dominance of brute-force to the dominance of the brain-power.

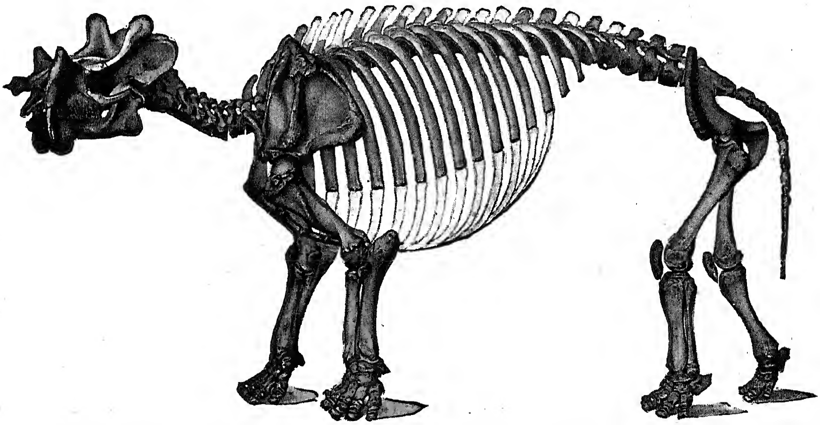


FIG. 429.—*Dinoceras mirabile*, restoration of skeleton by Marsh, about 13 feet long, Middle Eocene, Wyoming. (After Marsh.)

The divergence of the ungulates into odd- and even-toed.—Early in the Eocene, the hoofed animals began to diverge into their present divisions, the odd-toed (perissodactyls) and the even-toed (artiodactyls).

The distinction is not so much a matter of toes as of mode of support. In the odd-toed, the main line of support lies in the axis of the middle toe (*Mesaxonia*); in the even-toed, it lies between the third and fourth toes (*Paraxonia*); in other words, *one* main line of support in the first case, and *two* in the second. In the course of time, the lateral toes fell

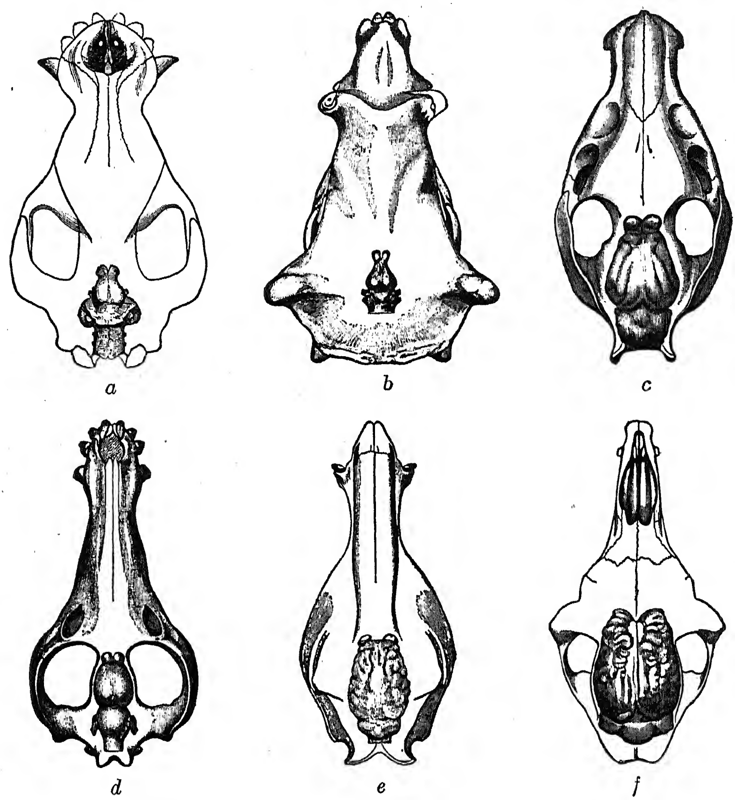


FIG. 430.—COMPARISON OF BRAINS. EOCENE BRAINS: *a*, *Coryphodon hamatus;* *b*, *Tinoceras pugnax.* MIOCENE BRAINS: *c*, *Eporeodon sociates;* *d*, *Elotherium crassum.* PLIOCENE BRAIN: *e*, *Platygonus compressus.* MODERN BRAIN: *f*, *Auchenia vicugna.* (After Marsh.)

out of use and were atrophied. The first class reached its extreme type at length in the horse, and the second in our cloven-hoofed cattle. But these perfected types were not attained in this period, which only witnessed the initial divergence. The original five spreading toes were not so advantageous on hard, grassy ground as a strong, concentrated line of support through the center of the foot, and as the toes were no longer

used for grasping or digging, as in the case of the carnivores, they gradually dwindled away. On the whole, the two-toed system seems to have proved the best; at least the artiodactyls are now much the more numerous.

The evolution of the perissodactyls did not pass beyond the three-toed form during the Eocene period. The three present types, the tapir, the horse, and the rhinoceros, were, however, distinctly foreshadowed. The most undifferentiated of the early perissodactyls were the lophiodonts, which seem to have graded almost insensibly into the ancestral tapirs (*Systemodon*), horses (*Hyracotherium*), and rhinoceroses (*Hyrochinus*). The first definite steps in the development of the horse, which has become a classic example of evolution, appeared in the second stage of the earlier Eocene (Wasatch), no traces having yet been found of the equine line in the Puerco. The earliest recognized form was the *Hyracotherium* (Fig. 431), whose equine characters are quite obscure.

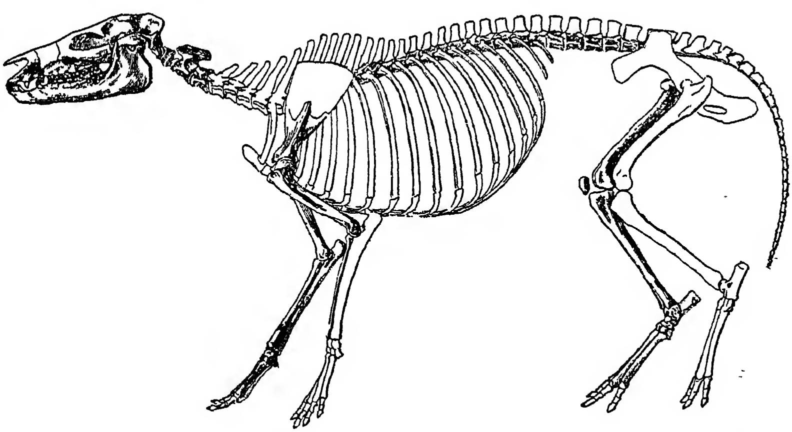


Fig. 431. — An early ancestor of the horse family, *Hyracotherium* (*Protorohippus*) *venticolum*, from the Lower Eocene (Wind River formation) of Wyoming, ¼ natural size. (Skeleton restored by Cope.)

Pachynolophus represented a slight step in advance, and the *Orohippus* (*Epihippus*) a more decided step. The latter was four-toed in front (three functional) and three-toed behind, and the limbs and teeth were slightly modified in the direction of the horse. These forms were about the size of a small dog, and as nearly canine as equine in appearance. The evolution continued through the remaining periods of the Tertiary, the true horse only appearing in the Pliocene. The primitive Eocene

forms lived both in Europe and America, and the evolution seems to have gone forward along much the same lines in both countries; but how far this implies free intermigration and how far parallel evolution is a mooted point.

The rhinoceros family appears in the record a little later than the tapirs and horses, and, although recognized in the later part of this period, had its development chiefly in the next.

A notable side branch of the tapir-horse-rhinoceros stem appeared in the later part of the period in the form of the titanotheres, which, in the next period, reached titanic dimensions and then soon became extinct.

The deployment of the artiodactyls.—The even-toed division emerged from the generalized type more slowly. Of the four present groups, *Pecora* (cattle, sheep, deer), *Suina* (pigs, peccaries, hippopotamuses), *Tylopoda* (camels, llamas), *Tragulina* (chevrotains), the second was represented in the Bridger epoch by a primitive hog (*Homacodon*) which was much smaller than the modern hog, and had strong canine teeth of somewhat carnivorous aspect. Strangely enough, the ancestral camels seem to have developed on the American continent in the middle and later Eocene, and to have flourished here until the Pliocene, when, having previously sent a branch to South America to evolve into llamas and vicunas, and another into the Old World to become the present camels, they died out in their primitive home. The forerunners of the ruminants appeared in a group of partially differentiated forms (*Cænotheridæ* and *Xiphontidæ*), and there was also a rather notable group of small artiodactyls, the oreodons, that seem to have left no descendants.

Amid all these changes in the more progressive branches of the condylarths and their descendants, the primitive type of condylarths lived on with minor modifications, but after the earliest Eocene, it became markedly inferior to its own more progressive kin.

The development of the carnivores.—As already noted, the ancestors of the carnivores, the creodonts, were not sharply distinguished from the primitive ungulates, the condylarths. It has been thought by some paleontologists that the creodonts were the more primitive stem, and that the condylarths diverged from them, as also the edentate and rodent branches. This would give the creodonts the central position among the primitive mammals. It has been suggested that they themselves may have branched off at an earlier date from some very

unspecialized insectivores. These views are chiefly valuable for their suggestiveness. The creodonts ranged throughout the whole period and passed into the next, gradually giving way meanwhile to their own more progressive offspring. They were common in America and in Europe, and there is evidence that they lived also in South America. The special modes of divergence of the present families is yet largely undetermined. There were anticipatory forms in the basal Eocene, but the modern types only began to emerge definitely toward the end of the period. *Patriofelis*, "the father of cats," a name not to be taken too

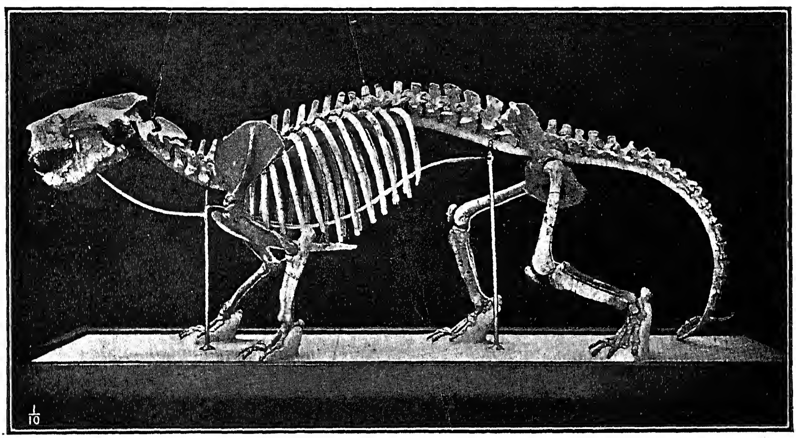


FIG. 431*a*.—Mounted skeleton of Patriofelis, a Creodont from the middle Eocene of Wyoming; $\frac{1}{18}$ natural size. (After Osborn.)

literally, of the Bridger epoch, presented a suggestive combination of characters, some features resembling those of the *Felidæ* and others those of the seals. Some species seem to have been aquatic. Primitive representatives of the dog family (*Canidæ*), thought to be descendants of the *Provivera* branch of the creodonts, appeared in Europe in the late Eocene period. The *Mustelidæ* (otters, badgers, and weasels) and the *Viverridæ* (civets, ichneumons, and their allies) appear to have had a common ancestral form in the early Eocene, and to have diverged in the later portion. There were ancestral weasels in the latter part of the period, as well as primitive viverroids. The ancestral hyenas appeared about the same time in Europe and Asia. The cat family had a forerunner in *Eusmilus* of the Upper Eocene of France, though but

little is known of the cats until the Miocene, when they were abundant and wide-spread.

The emergence of the edentates.—The ancestral edentates, the *Ganodonta*, were very similar in general appearance to the *Condylarthra* and *Creodonta*, but their dentition and certain peculiarities of structure brought to knowledge by the researches of Wortman and Osborn have led to the recognition of their edentate relations. The slight degree of differentiation in the earliest Eocene seems to imply that the three orders had but recently diverged from their common ancestors. Wortman holds that the South American edentates were derived from these northern forms and that there must hence have been a land connection about the time of the early Eocene, which permitted their migration. It is not improbable that such a connection was formed during the transition epoch from the Cretaceous to the Eocene, which might have continued long enough to serve this function without permitting a migration of all forms.

The ancestral rodents.—In the early Eocene there were very primitive rodents whose incisors had just begun to assume their specific gnawing functions. By the middle of the period they became a notable factor

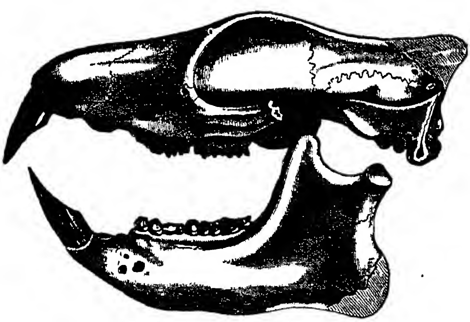


FIG. 432.—The skull and jaw of a large Eocene rodent, *Tillotherium fodiens* Marsh, from the Bridger formation, Wyoming, about ⅙ natural size.

of the fauna in the form of tillodonts, the *Tillotherium* of the Bridger formation having finely specialized incisors (Fig. 432). For a rodent, this was a large animal, half the size of a tapir. The primitive squirrel type appeared in Europe in the latter part of the period. Even to-day, the rodents retain many primitive characters, and since the Miocene they have undergone few radical changes. This slow evolution implies

that they may have extended farther back than the record indicates. Their derivation is not yet determined.

The primitive insectivores.—Most of the present families of insectivores can be traced back to the Eocene. They retain even to this day many of their primitive characters, agreeing with the creodonts in their low type of brain and in some skeletal features. They are the least altered of the great branches, and have been thought to most nearly represent the character and habits of the primitive placentals, but this remains an open question.

The primates (Quadrumana).—Of the higher order of the primates, the apes, no traces have yet been found in the Eocene deposits, the earliest apes appearing about the middle of the Miocene. Of the lower division, the lemuroids, representatives appeared in the Wasatch in America and in a similar horizon in Europe, a distribution which is the more notable as the lemurs are now confined to Madagascar and to portions of Africa and southern Asia. The progress of investigation is gradually filling up the gap between the lemuroids and the apes, and there is now little doubt that the apes are descendants of the early lemuroids. The latter show many affinities to the insectivores, and were possibly derived from them. The *Anaptomorphus* from the Wasatch of Wyoming had large cerebral hemispheres of the type characteristic of the primates. This must have contrasted strongly with the small smooth brains of the contemporaneous creodonts and condylarths and their derivatives.

The mammals go down to sea.—Just as the land reptiles of Mesozoic times took to the sea by choice or by necessity, so did the mammals in Cenozoic times, and thus arose the cetaceans (whales, dolphins, porpoises), the sirenians (manatees, dugongs), and the pinnipeds (seals, sea-lions). Some suggestion of the possible origin of the last is found in *Patriofelis*, but the source of the cetaceans and sirenians is quite uncertain. The latter have not yet been found in the Eocene deposits, but the primitive cetaceans had representatives in the *Zeuglodons*, whale-like animals of great length, whose limbs had become fully adapted to an aquatic life, but whose dentition remained that of land animals. While widely distributed, their preferred habitat seems to have been the southern part of the Atlantic coast of the United States. In a certain district in Alabama the vertebræ were originally so abundant as to attract much popular attention and call forth legends of divers catastrophes.

The non-placentals.—If the non-placentals of the northern continents had any kinship to the foregoing placentals, they failed to show it by any special awakening in this time of marvelous placental evolution. In the basal Eocene beds there were somewhat more and larger forms than in previous periods, and during the Eocene, early forms of the opossum (*Didelphys*) appeared in both the Old and New World. The opossum retained this wide distribution until the Miocene, when it disappeared in Europe, but has remained in North and South America to the present time.

The birds.—If compared with the singular record of the Cretaceous, the deployment of the birds was very marked. So diverse forms as ancestral gulls, herons, flamingoes, albatrosses, buzzards, falcons, eagles, owls, woodcock, quails, plovers, and ostrich-like, flightless birds of great size, with not a few forms of doubtful interpretation, had appeared.

The reptiles and amphibians.—One of the greatest contrasts in geological history is found in comparing the size, power, and multitude of the Cretaceous land reptiles with those of the following Eocene. Of the great saurian herd of the Mesozoic only a few forms lived over into the very earliest Eocene epoch (Puerco), and these shortly became extinct, and with their extinction the saurians disappeared. True land reptiles seem to have become rare. There were turtles on both land and sea, and some of them attained a large size. There were crocodiles which belonged about equally to land and water; also snakes, some of which were python-like in form and attained large dimensions. The amphibians were present beyond doubt, but, judging from the fossil remains, they formed a very insignificant factor in the fauna.

The insect life.—When so much must be omitted, it is unwise to dwell on changes that do not have significant bearings on historical progress, and it may now be summarily remarked, on the authority of Scudder,[1] that there has been but little important change in the insect world since the beginning of the Cenozoic era, almost no new orders or even families having appeared, though the genera and species have changed.

No very significant change is known in the molluscan or other forms of terrestrial life not already noticed, nor in the fresh-water life.

[1] Mon. XXI, U. S. Geol. Surv., 1893, p. 1.

The Marine Life.

The very name Eocene, founded upon the presence of a small percentage of *living* species, implies the stage reached by the marine invertebrates. Not only were the existing orders, families, and genera established, with some exceptions, but even the present species had begun to appear. The changes that follow from this time on are valuable as criteria of correlation, climate, migration, and other elements

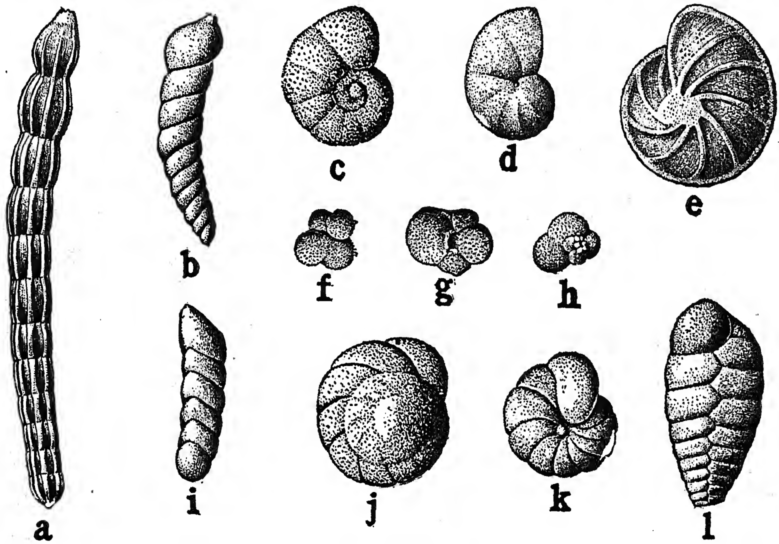


FIG. 433.—EOCENE FORAMINIFERA: *a, Nodosaria bacillum* Defrance; *b, N. communis* (d'Orbigny); *c, Anomalina ammonoides* (Reuss); *d, Cristellaria gibba* d'Orbigny; *e, C. radiata* (Bornemann); *f, g,* and *h, Globigerina bulloides* d'Orbigny; *i, Vaginalina legumen* (Linné); *j, Discorbina turbo* (d'Orbigny); *k, Truncatulina lobatula* (Walker and Jacob); *l, Textularia subangulata* d'Orbigny. Magnified 10 to 50 times. (Maryland Geological Survey.)

of the later history, but they do not record any further profound biological transformations. They stand in striking contrast with the radical and rapid evolution of the placental mammalians.

Geologically, the most striking feature of the marine Eocene life was the extraordinary abundance and size of the foraminifers. Massive beds of limestone in the Paris basin were largely made up of the tests of *Miliola.* Other Eocene limestones were formed chiefly of *Orbitolites, Orbitoides, Operculina,* and *Alveolina,* while the nummulitic limestone, whose wide range and great importance has already been indi-

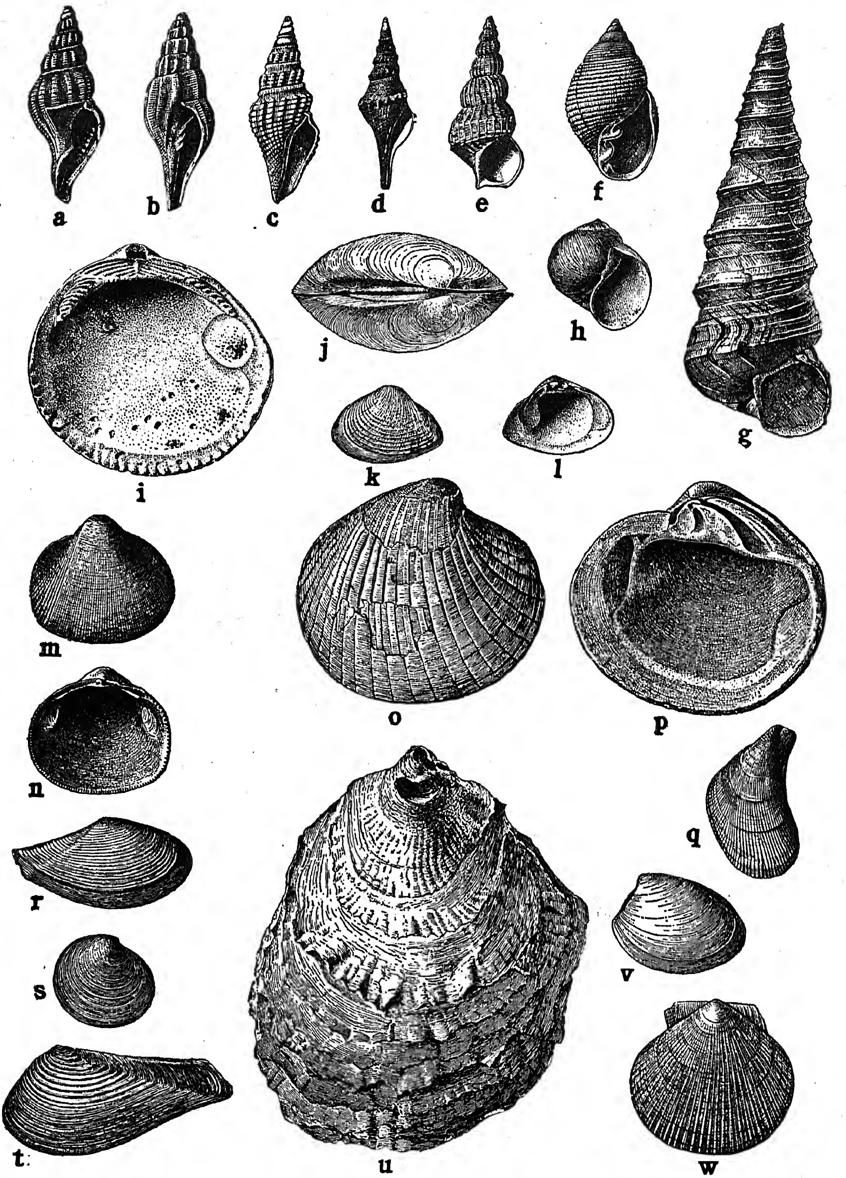


FIG. 434.—EOCENE MOLLUSCS: GASTROPODS: *a, Fusus* (?) *interstriatus* Heilprin; *b, Mitra potomacensis* Clark and Martin; *c, Pleurotoma tysoni* Clark and Martin; *d, P. potomacensis* Clark and Martin; *e, Scala potomacensis* Clark and Martin; *Tornatellæa bella* Conrad; *g, Turritella mortoni* Conrad; *h, Lunatia marylandica* Conrad. PELECYPODS: *i, Glycymeris idoneus* (Conrad); *j, Dosiniopis lenticularis* (Rogers); *k* and *l, Corbula aldrichi* Meyer; *m* and *n, Protocardia levis* Conrad; *o* and *p, Venericardia marylandica* Clark and Martin; *q, Modiolus alabamensis* Aldrich; *r, Leda parilis* (Conrad); *s, Lucina aquiana* Clark; *t, Crassatellites alæformis* (Conrad); *u, Ostrea compressirostra* Say; *v, Nucula ovula* Lea; *w, Pecten choctawensis* Aldrich. (After Maryland Geological Survey.)

cated, was made up largely of the coin-like *Nummulites,* which lived in prodigious abundance. The gastropods and pelecypods of modern types became very prolific, while the cephalopods were markedly less important than in the Cretaceous. The nautiloids were more abundant than now, while the sepioids have left little record. The sea-urchins continued to be abundant, the corals had taken on the modern forms, and the decapods were rising in importance.

The American Eocene faunas were rather pronouncedly provincial, though there was a minor list of species of rather wide range, binding the provinces together. This condition is assignable to the previous restrictive movement, and to the fact that the shallow-water tract was only a border belt and subject to much variation from point to point. So true is this, that much difficulty is experienced in making a confident correlation between the formations in different sections even along the Atlantic and Gulf coasts. Much greater difficulties arise when the regions are more widely separated. The variations are, however, variations of detail, not of broad features that can be readily sketched. For these, reference must be had to the paleontological reports on the regions involved.[1]

THE OLIGOCENE EPOCH.

In North America.—As already stated, formations corresponding to the Oligocene of Europe have not usually been differentiated, in North America, from the Eocene below and the Miocene above. Recently, however, the differentiation has been gaining ground, and may be justified for the reasons set forth on pages 194–5, or on paleontological grounds, if it is desirable to make the classification for this country conform as closely as possible with that of Europe.[2]

Certain beds along the Atlantic coast (Cooper River marl, and per-

[1] W. H. Dall, Tertiary Fauna of Florida, Trans. Wagner Free Inst. Sci., Vol. III, Pts. 1–5, 1890–1900, finely illustrated; Bull 141, U S. Geol. Surv., 1896, and other papers therein referred to W. B Clark, Md Geol. Surv, Eocene volume, 1901, finely illustrated, full bibliography, q v. R M Bagg, Bull 141, U. S. Geol. Surv., 1893, Protozoa. A Heilprin, Comp. Eocene Mollusca of Ulwich, Europe, Proc. Acad, Nat. Sci Phil., Vol. XXXI, 1879; Vol. XXXII, 1880; and Vol. XXXIII, 1881; Jour Acad. Nat. Sci. Phil, Vol. IX, 1884. T. W. Vaughn, Cœlenterata, Bull. 141, U. S Geol. Surv., 1896; Corals, Mon. XXXIX, U. S. Geol. Surv., 1900. T. W. Stanton Eocene of Pacific Coast, 17th Ann. Rept U. S. Geol. Surv., Pt. I, 1895–6. Gilbert D. Harris, Am. Pal. Bull., Vols. I and II.

[2] For table of Oligocene formations, see Dall, 18th Ann. Rept. U. S. Geol. Surv., Pt. II.

haps the Ashley River marl) formerly regarded as late Eocene are now classed as Oligocene. The Ashley River marls of North and South Carolina contain nodular phosphate of lime, locally in such quantities as to be commerically valuable.[1] The Chattahoochee and Chipola beds of Florida are regarded as late Oligocene,[2] and their fossils indicate a climate warmer than that of the Miocene (Upper Miocene of the older classification). Oligocene has been suspected on the Atlantic coast as far north as New Jersey.[3]

The principal formations of the Gulf region which have been correlated with the Oligocene of Europe are the Vicksburg (below) and Grand Gulf formations[4] of Alabama, Mississippi, and Louisiana, and the Fayette[5] formation of Texas. The Vicksburg formation (Lower Oligocene) is chiefly limestone, and is closely associated with the Eocene (Jackson) limestone of the same region (p. 199). The Grand Gulf and Fayette formations are made up of sediments which seem to have been brought to the Gulf by the drainage of the present Mississippi basin, and by that of the lesser basins bordering it on either hand. The landward parts of these formations are non-marine, while the seaward parts may be marine. The presence of gypsum in the Grand Gulf series gives some suggestions of local conditions, and perhaps of climate. In contrast with most other clastic formations of similar age along the Atlantic seaboard, the Grand Gulf series contains firm sandstone, some of which is even quartzitic.[6]

The Oligocene, especially the early Oligocene, is represented somewhat generously about the Caribbean Sea, where its association with the Eocene is generally close,[7] and its separation from the Miocene distinct. This is in keeping with the phenomena of the Gulf States. Limestone is the dominant type of rock in the Antillean region.

[1] Penrose Bull., 46, U. S. Geol. Surv.

[2] Dall, op cit.

[3] Dall, Md. Geol. Surv., Miocene, p. CXLI.

[4] Smith, Geol. Surv. of Ala., 1894. See also Dall, 18th Ann. Rept. U. S. Geol. Surv., and Maury, A Comparison of the Oligocene of Western Europe and Southern United States, Bull. Am. Pal , No. 15, p. 43.

[5] Penrose, Geol. Surv. of Texas, 1st Ann. Rept.

[6] The classification of the Grand Gulf formation is in dispute. Some of the beds described under this name are probably younger than Oligocene. See Smith and Aldrich, Science, New Series, Vol. 16, p. 836, and Vol. 18, p. 26.

[7] Hill, Geology and Physical Geography of Jamaica, and Geological History of the Isthmus of Panama and portions of Costa Rica. Bull. Mus. Comp. Zool., Vols. XXVIII and XXXIV respectively.

The Oligocene is likewise represented among the terrestrial deposits of the western part of the continent. Following the Uinta stage (p. 209) of the Eocene, physiographic and drainage relations were so changed as to shift the sites of notable sedimentation. The next considerable formation, the history of which is partially known, is the *White River* formation, lying east of the northern Rockies. It occupies an extensive area in northeastern Colorado, southeastern Wyoming, western Nebraska (Brule and Chadron formations [1]), and South Dakota, and it may extend southward even to Kansas.[2] Clastic sediments pre-

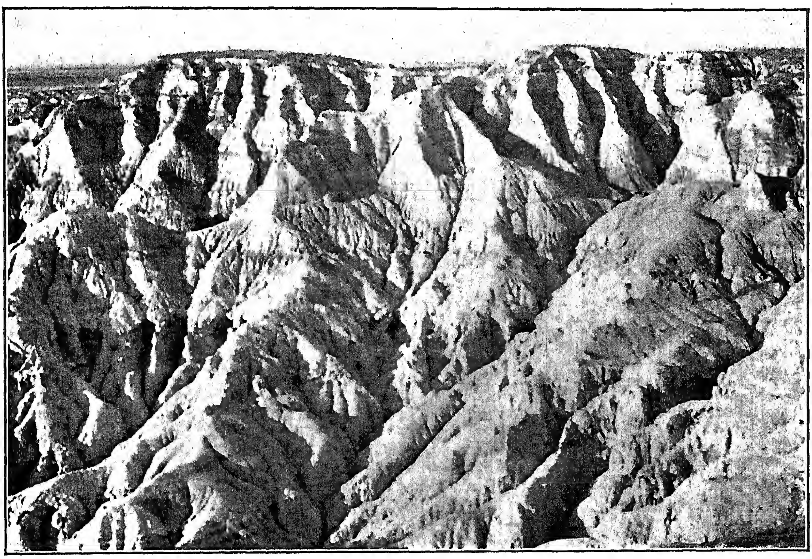


FIG. 435.—Bad Land erosion in the Brule clay, near Scotts Bluff, western Nebraska. (Darton, U. S. Geol. Surv.)

dominate in the White River series, and clay predominates over coarser material, but beds and lenses of sandstone and conglomerate (or sand and gravel) occur at various places, and there are thin beds and lenses of limestone and some volcanic ash.

The origin of the White River beds has been the occasion of much difference of opinion. They have usually been described as lacustrine, but in recent years parts of them have been regarded as partly or

[1] Darton, Camp Clarke, Scotts Bluff, Edgemont, and Oelrichs folios, U. S. Geol. Surv.
[2] Adams, Am. Geol., Vol. 29, p. 303.

wholly fluviatile,[1] and even as eolian.[2] The eolian origin has been urged on the basis of the fossils, which are chiefly those of land animals (land tortoises and mammals); but while much may be said for this hypothesis as applied to parts of the formation, it does not seem applicable to all of it, as the constitution of the beds shows. Gypsum, barite, etc., in the series give some hint of the climatic conditions of the time. In the light of present knowledge, it seems probable that all phases of land aggradation, lacustrine, fluvial, and eolian, are represented in the

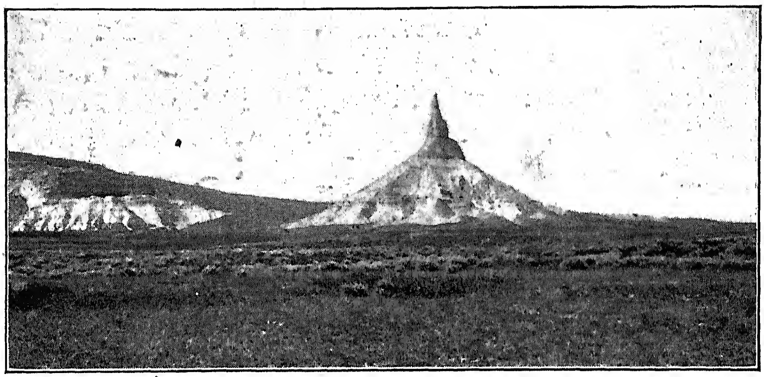


FIG. 436.—Chimney Rock, a detail in the Bad Lands of the White River country. The base of the column is Brule clay. (Darton, U. S. Geol. Surv.)

series. The formation is said to have originally covered most of the Black Hills region, and possibly all of it,[3] for remnants are now found up to elevations of more than 6000 feet, and the highest points of the Hills are but little higher; but in so far as running water and wind were concerned in its deposition, the present altitude and attitude of the beds cannot be relied on as a measure of former extension or later deformation.

In these and other comparable formations, well-defined bedding has often been relied on as conclusive evidence of lacustrine origin; but it should be remembered that eolian sand is often as distinctly stratified as that which is deposited by water (Fig. 437). The stratification

[1] Fraas, Science, Vol. 14, N. S., p. 212, holds that the earlier White River beds were fluviatile, and that later ones were lacustrine.

[2] Matthew, Am. Nat., Vol. XXXIII, p. 403, 1899.

[3] Darton, 19th Ann. Rept. U. S. Geol. Surv., Pt. IV; 21st Ann. Rept. U. S. Geol. Surv., II.

developed by the wind may often be distinguished from that developed by water, but it is not clear that the distinction can always be made where exposures are limited (Fig. 437).

In Colorado there was a small area of deposition in the South Park. The beds (*Florissant*) deposited here consist largely of volcanic ash, and are famous for the extraordinary number of insects which they contain.

Some of the John Day beds of Oregon,[1] unconformable above the

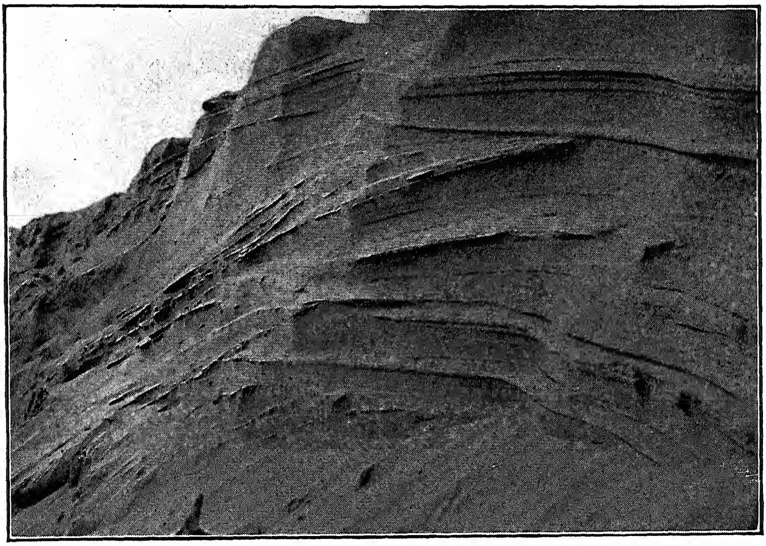


Fig. 437.—Section of stratified dune sand (recent). South end of Lake Michigan. (Bastin.)

Eocene (Clarno), are probably to be referred to the Oligocene. This area of aggradation occupied but a few hundred square miles, but in it sediments accumulated to a thickness which has been estimated at several thousand feet. They consist, in considerable part, of volcanic ash and tuff. The youngest of the John Day beds seem to be younger than the White River beds, and perhaps should be classed as Miocene. The John Day beds, Oligocene and later, appear to be largely of eolian origin, but the upper part of the series contains fresh-water shells.[2]

[1] Dall, 19th Ann. Rept. U. S. Geol. Surv.; Merriam, Jour. Geol., Vol. IX, pp. 71–2, and Bull. Univ. of Cal., Vol. II, p. 270 et seq.

[2] Merriam, Bull. Univ. of Cal., Vol. II, p. 270 et seq.

The marine Oligocene is also represented in western Oregon[1] (Aturia and Astoria beds), and the earliest Tertiary deposits of British Columbia (non-marine) are now referred to the Oligocene.[2] They contain some coal, and antedate the Tertiary volcanic activity of the region.

Beds referred to the Oligocene are wide-spread in Alaska,[3] where they are sometimes carboniferous, and little disturbed. Here belongs the thick Kenai series (said to be 10,000 feet) unconformable on Eocene.[4] Certain fossiliferous beds of western Greenland seem to be of the same age as the Kenai series.

Considerable geographic changes occurred during the Oligocene, or at its close, especially in the Gulf and Carribbean regions.[5] In both regions, the Oligocene (early Oligocene) beds are commonly conformable on the Eocene and unconformable beneath the Miocene; and in the latter, there was a notable deformation and increase of land during the Oligocene or at its close.

The biological effects of the physical changes about the Gulf of Mexico and the Carribbean Sea at about this time have already been referred to.

Foreign.

Europe.—The Oligocene is more distinctly differentiated from the Eocene in Europe than in most parts of America. Toward the close of the Eocene, the epicontinental sea of northern Europe was excluded from some areas which it had covered during that period, but the changes which converted the Eocene areas of deposition into land were probably slight, since after their occurrence considerable areas stood so near sea-level that slight changes of altitude served to greatly restrict or extend the epicontinental waters. How far the restriction of the sea at the close of the Eocene was the result of surface warping, and how far the result of the filling of shallow basins with sediment, is unknown.

At the beginning of the Oligocene period, the sea transgressed considerable areas of Germany which had been land in the Eocene period.

[1] Dall, op. cit , and Diller, 17th Ann. Rept. U. S. Geol. Surv.

[2] Dawson, Science, March 15, 1901.

[3] Schrader, Bull G S. A., Vol. 13, p. 248, and Brooks, p. 261.

[4] Dall, Trans. Wagner Free Inst., Vol. VI, 1903, p. 1548. See also Dall, 18th Ann. Rept. U. S. Geol. Surv., Pt. II, and Spurr, Pt. III. The Kenai formation was formerly classed as Eocene.

[5] See references to the writings of Hill under Eocene.

At the time of its maximum extension (Middle Oligocene, Fig. 438), the epicontinental sea of the period covered much of north Germany, and the North Sea was connected with the Mediterranean, and extended to southeastern Russia, and even to the Aral sea.[1]

The oldest Oligocene deposits of central and western Europe are largely of terrestrial, fresh- and brackish-water origin. Local deposits of salt and gypsum show that there were local bodies of water of excessive salinity.

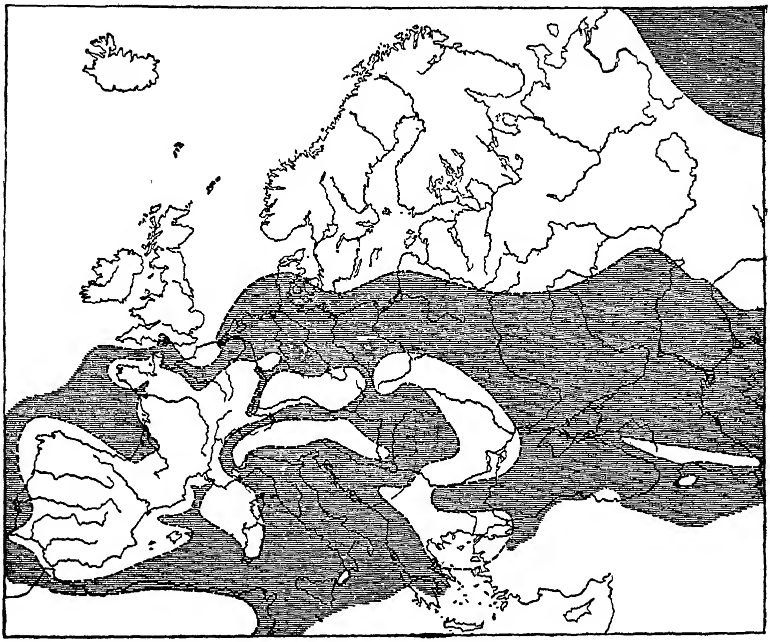


Fig. 438.—Sketch-map of Europe in the Middle Oligocene. The shaded part shows area of deposition. (After De Lapparent.)

In Britain, the Oligocene has but slight representation, being found in one small area (Hampshire basin and Isle of Wight) only. As in most other parts of Europe, the beds are partly marine and partly non-marine. Some of the igneous rocks of the islands about north Scotland may have dated from this period. The Oligocene is represented in the Paris basin, partly by marine beds, partly by beds deposited in brack-

[1] Kayser, Geologische Formationskunde, p. 479.

ish water, and partly by beds of fresh-water origin. They lie unconformably on older formations. They include sands, marls, arkoses, and limestones, some of which are of fresh-water origin (snail-shells, caddis worms, chara, etc.). Coal is also present, and the conifers and cypresses which entered largely into its composition, together with the leaves of the oak, laurel, cypress, fig, maple, birch, etc., which occur in the associated clastic beds, give some notion of the aspect of the vegetation and of the climate. Basaltic tuff is interbedded with the other formations, showing that the igneous activity of the region dates back to this period. In central and eastern France, there is a bed of earth so full of pisolitic grains of limonite as to be worked as iron ore. With it are beds of limestone of fresh-water origin, sometimes containing so many bones as to be a source of commercial phosphate of lime. These phosphate deposits sometimes (Quercy) occur in pockets and fissures in the Jurassic rocks on which the Oligocene lies. The Oligocene of France is divided into three principal series, the Tongrian (largely brackish) below, the Stampian (chiefly marine) in the middle, and Aquitanian (lacustrine) at the top.

In Belgium, the Tongrian is represented by marine beds below and fluvio-marine above. The Middle series (Rupelian) is also partly marine and partly non-marine, while the Upper is wanting.

The Oligocene of north Germany is mainly marine, yet there are local beds of coal, fresh-water limestone, and other formations of non-marine origin at various points. Conditions for land deposition indeed seem to have been rather common about the borders of the areas which the sea covered, especially early and late in the period. Locally, coal-beds have extraordinary thickness (70 meters at Lutzendorf).

The Oligocene of southern Europe is chiefly marine, but in the upper part of the series, lake and marsh deposits are not rare. In Italy it has been estimated to have the extraordinary thickness of nearly 12,000 feet. The series is partly marine and partly terrestrial.

In Switzerland, the Oligocene is represented by the upper part of the Flysch formation, which overlies the Lower Nummulitic limestone (p. 217), and by the lower part of the Molasse, which overlies the Flysch. The Flysch (5200 feet) is marine, while that part of the Molasse referred to the Oligocene, is largely non-marine.

The Oligocene is also represented in the Vienna basin. The Aquitanian stage is represented by marine and non-marine beds of sediment

and coal. Locally, the beds are now nearly vertical, and their disturbance, accompanied by great outpourings of lava, seems to have begun before the close of the Oligocene period. About the Dardanelles, the Oligocene is non-marine, and coal-bearing.[1] Farther south, the system is not all marine. Among the non-marine formations is coal. The fossils of southern Europe indicate some such climatic conditions as those of the Mexican Gulf coast at the present time.

In Europe, as in North America, there were considerable igneous eruptions during the Tertiary, and especially during the Oligocene. The results are to be seen in Bohemia, where there is much igneous rock, and in northern Ireland and western Scotland, where outpourings of lava probably made great plateaus, of which some of the adjacent islands are remnants, in Iceland, and in the Vienna basin. Between eruptions, vegetation grew in the marshes and shallow lakes and over the surface of the lava. The substance of this vegetation is locally (Faroes, and Iceland) preserved in the form of coal between the lava-beds. Some of the lakes of France seem to have been obliterated by volcanic action.

Amber.—One of the peculiar formations found in the Lower Oligocene is the amber of northern Germany. This is found principally in the vicinity of Königsberg. While amber in small quantities is found in Sicily and a few other places, that of the Baltic region is more abundant than that of any other part of the earth, so far as now known. Amber is fossilized resin, apparently from certain varieties of coniferous trees. Its original position in the Baltic region appears to be in certain glauconitic beds of a clayey nature, but parts of this formation have been worn by the waves, and the amber distributed. Some of that which finds its way into commerce is picked up on the Baltic shore, while some is taken from the beds in which it was originally entombed.

One of the interesting features of the amber is the fact that it frequently contains insects. The insects seem to have alighted upon the resin while it was soft, and to have become completely immersed in it, and perfectly preserved. About 2000 species have been found thus entombed. Subsequently, by the escape of its volatile portions, the resin became hard, and was ultimately changed to amber. The amber of the Baltic region was known to the Phœnicians, who appear to have made trips to the region for it.

[1] English, Q. J. G. S., 1904, p. 246.

Bohnerz.—In southwestern Germany, and in parts of France and Switzerland, there are peculiar and interesting mineral-spring deposits (Bohnerz formation) yielding abundant fossils. This formation occurs mainly near the outcrops of the White Jura. The mineral matter deposited from the springs incased many bones of mammalia, as well as the bodies of other animals. On the decay of the organic matter, perfect molds of their forms were preserved. By being properly filled, excellent casts even of delicate parts of flowers and insects are sometimes obtained. The name *Bohnerz* refers to bean-like concretions of iron ore.

Other continents.—On other continents, the Oligocene has not been generally differentiated. It is known in northern Africa, a part of the Mediterranean province, and perhaps in Soudan.[1] It is known in Patagonia, where it is partly marine[2] and partly non-marine, and it may be widely distributed outside of Patagonia. The Oligocene of the Antillean and Central American regions has already been referred to. In Panama, nummulitic limestone occurs.[3] In New Zealand, igneous rock is associated with the sedimentary beds of this epoch.

The Life of the Oligocene.

The vegetation.—The mixed evergreen and deciduous forests of the Eocene merged into very similar ones in the Oligocene, particularly in Europe. There palms continued to be abundant and varied, growing even in north Germany, and being richly displayed in southern France and northern Italy, especially in Liguria. They seem to have become rare, however, in the United States, for in the Florissant sediments, which are rich in plant fossils as well as insects, palms are barely represented. The Florissant fossils imply a return to a diversified angiosperm flora. Of 160 species identified by Lesquereux, 133 were angiosperms against 8 conifers, while 19 belonged to lower orders. The conifers were represented by pines, yews, and sequoias which closely resembled those of Europe, where they were relatively more abundant. The variety of the angiosperms was great, and widely distributed

[1] De Lapparent, La Geographie, Vol. XI, p. 1.

[2] Hatcher. See references to this region under Eocene, and especially Geol. Mag., 1902, p. 136.

[3] Bertrand and Zurcher, Etude Géologique sur l'Isthme de Panama (Rev. in Geol. Mag., 1903, p. 419).

through the several orders that are now found in the latitude of the middle and southern States.

The land animals.—As already indicated, the Florissant beds are phenomenally rich in fossil insects, and fishes also were abundant. Both classes had a modern aspect of the middle temperate phase, but all the species of insects, of which over 700 have been described by Scudder,[1] are extinct. This seems to indicate that although the types had all become modern, the species continued to evolve with relative rapidity. In this respect the insects stand between the more slowly evolving marine invertebrates and terrestrial plants on the one hand, and the more rapidly evolving mammals on the other. The rapid development of the mammals perhaps finds part of its explanation in their progressive adaptation to the angiospermous vegetation. The mammals continued their rapid evolution without interruption, and perhaps even with some acceleration, assisted by the moderate extension of the land and good migratory connections with Europe. The *Carnivora* proper came into clear definition, and were represented in the White River beds by ancestral dogs (*Daphænus, Cynodictis, Cynodesmus*), cats (*Dinictis, Hoplophoneus, Eusmilus*), coons (*Phlaocyon*), and weasels (*Bunælurus*), while some creodonts remained. The rodents were represented by squirrels (*Sciurus*), beavers (*Steneofiber*), pocket-gophers (*Gymnoptychus*), rabbits (*Palæolagus*), and mice (*Eumys*). Among the perissodactyls, the rapidly developing horse family presented the forms *Mesohippus* and *Anchippus*. There were also lophiodonts (*Colodon*), tapirs (*Protapirus*), rhinoceroses (*Leptaceratherium* and *Aceratherium*), and the related *Hyracodon* and *Metamynodon*, as well as gigantic titanotheres. The artiodactyls took on the extinct forms of *Anthracotherium, Hyopotamus, Elotherium*, and of oreodons, as well as ancestral peccaries (*Perchœrus, Thinohyus*), camels (*Poebrotherium, Protomeryx*), ruminants (*Leptomeryx, Hypertragulus, Hypisodus*), and the singularly specialized horned and tusked *Protoceras*, making the artiodactyls a very important group. There were also insectivores (*Ictops, Mesodectes*), and marsupials referred doubtfully to the genus *Didelphys*, the opossum.[2] Many of the foregoing were present also in Europe, where there were also shrews, moles,

[1] The Tertiary Insects of North America, U. S. Geol. Surv. Ter., Vol. XIII, 1890; Mon. XXI and XL, U. S Geol Surv., 1893 and 1900.

[2] The classification of W D. Matthew is here followed. Bull. Am. Mus. Nat. Hist., Vol. XII, 1899, Art. III pp. 19–75.

muskrats, martens, civet cats, and various xiphodonts and anoplotheres, as well as extinct forms.

The rhinoceros tribe had deployed into three notable branches, one a true lowland form, ancestral in type to the existing family, another aquatic (*Metamynodon*), and a third an upland, horse-like, running form (*Hyracodon*). The *Metamynodon* was massive and stocky, like the modern rhinoceros, but hornless, while the *Hyracodon* was light-limbed and equine in many features, re-asserting the ancestral alliance

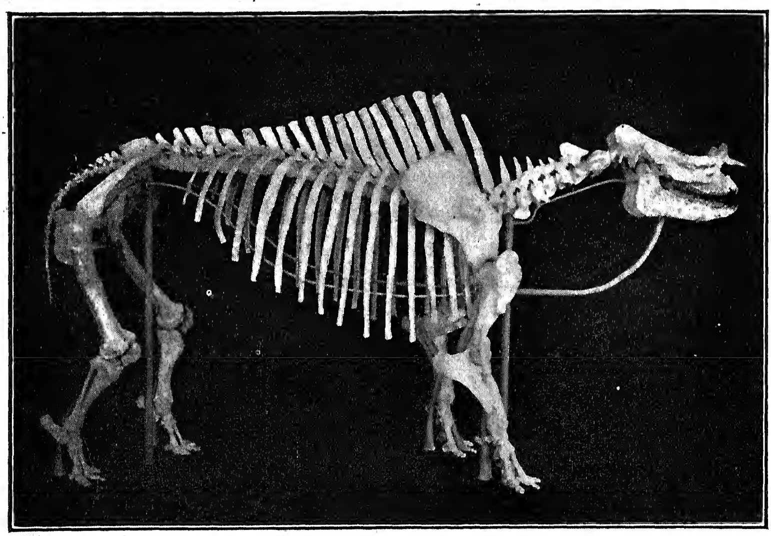


Fig. 439.—*Titanotherium validum* Marsh, photograph of a mounted specimen in the Carnegie Museum, by Director Holland.

of the horses and rhinoceroses. The tribe had a cosmopolitan range and was well represented in Europe.

The titanotheres were a massive erratic branch of the odd-toed ungulates which arose late in the Eocene, reached their climax in the Oligocene (White River), and then suddenly disappeared. They were intermediate in proportions between the rhinoceros and the elephant, and were distinguished by a long, depressed skull armed with a pair of horns near the extremity of the nose, as were their kin the rhinoceroses, but placed transversely, as in the ox (Fig. 439). They reached some fourteen feet in length and ten in height. There were many variations with age and sex, and several genera have been founded on these

variations (*Brontops, Titanops, Megaceratops, Diconodon, Haplacodon, Symborodon, Menodus*). They were American and apparently rather local in distribution.

The elotheres were large pig-like animals, constituting a temporary, highly specialized side branch of the even-toed ungulates, allied to the *Suidæ*. They appeared in North America in the White River stage, and continued into the John Day (Miocene) stage, and were present

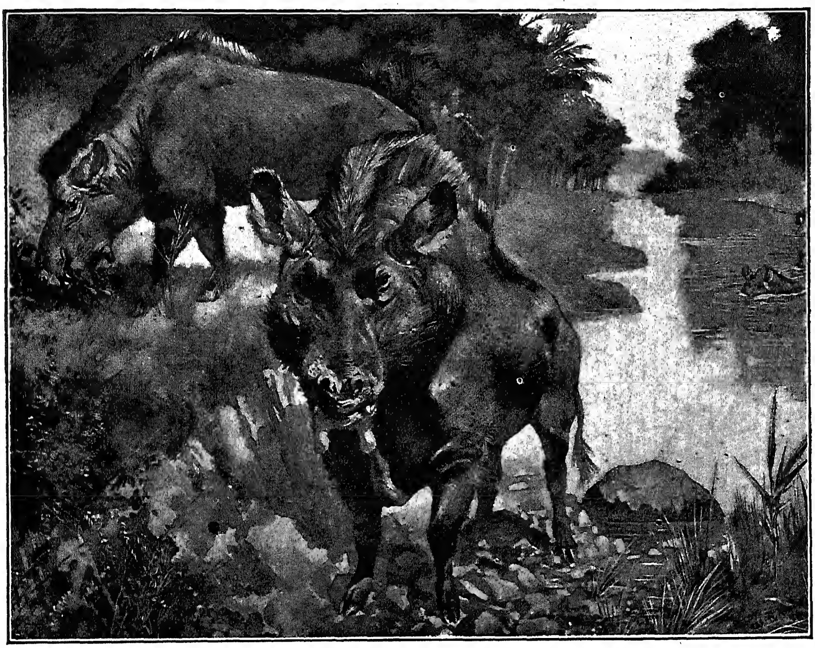


FIG. 440.—An interpretation of the general appearance of the elotheres, or giant pigs, of the White River epoch, drawn by Charles R. Knight under suggestions from Osborn and Scott, based on a skeleton in the Princeton Museum. (From drawing in American Museum of Natural History. Copyrighted by the Museum.)

also in Europe. An interpretation of their general appearance by Knight is shown in Fig. 440.

The *Protoceras* was remotely related to the deer family, and was profusely and strangely horned, as though in diminutive mimicry of the *Dinocerata*. There was, in the male, a blunt pair of protuberances between the ears, a pair of basal cores between the eyes, and two large prominences on the nose. The skull was only eight inches long, and the animal about the size of a sheep. It was North American (White

River) so far as known, and may be regarded as foreshadowing the deer (*Cervidæ*). Being a highly specialized form, it had a short career, as specialized forms usually do.

In a similar way the ruminants seem to have been introduced or foreshadowed by the *Tragulidæ*, the chevrotains, which are now represented in Farther Asia by a slender little ruminant, isolated and scarcely known, the *Tragulus*, "the scarcely altered survivor of a great tribe which flourished abundantly in Europe, and less so in North

FIG. 441.—Skull of a *Protoceras*-like animal (*Syndyoceras cooki* Barbour), recently discovered in the Loup Fork beds of Nebraska. (Photo. by Barbour.)

America, before the typical and fully differentiated ruminants had made their appearance." [1]

The oreodons were small animals, never exceeding the size of a large dog, and are interesting chiefly as a primitive form that lived on from the Eocene with little change, while its contemporaries were either rising to climaxes and disappearing, or were evolving into modern and more lasting forms. They seem to have been exclusively North American, and lived on till the late Miocene.

[1] A. Smith Woodward, Vert. Pal., p. 360.

The marine life.—If the Vicksburg formation be regarded as Oligocene, the general aspect of the Eocene sea life must be regarded as continuing into that period. Foraminiferal deposits (of *Orbitoides* in particular) are a notable feature, corresponding in phase with the nummulitic formations of the late Eocene. With these were also many pelecypods and gastropods, giving a decidedly molluscan cast to the fauna.

In the later stages of the American Oligocene, provincialism became very pronounced, and the correlation of beds, even in the same province, has been the subject of much difference of opinion.[1] The foraminifers having greatly declined, the fauna was overwhelmingly molluscan.

In Europe, provincialism was also very pronounced. Local and transient faunas, shifting to meet the changing relations of sea and land, were the characteristics of the time. No single great fauna like the nummulitic of the Eocene appeared, but chiefly molluscan assemblages here and there, and now and again, as the shallow shifting phases of the sea gave local embayments for temporary occupation.

[1] Details can best be reached through Dall's papers, Tertiary Fauna of Florida, Trans. Wagner Free Inst. of Sci., Vol. III, Pts. 1–6, 1890–1903; North Am. Ter. Horizons, 18th Ann. Rept. U. S. Geol. Surv., 1898, Pt. II, and the references in these, and Maury's Comparison of Oligocene of Western Europe and Southern U. S., Bull. Am. Pal. No. 15, Cornell Univ., 1902, and references contained.

CHAPTER XVII.

THE MIOCENE PERIOD.[1]

THE distribution of the Miocene beds (see map, Fig. 442) shows that the geography of the North American continent during the Miocene period was much the same as during the Eocene. The slight emergence of the Atlantic and Gulf coastal belts after the Eocene (or early Oligocene) was followed by a slight submergence of the same regions during the Miocene. Locally, and perhaps generally, along the Atlantic coast, the Miocene submergence exceeded the Eocene. The Mississippi embayment of the Miocene was less extensive than that of the Eocene, having been constricted by the partial filling or emergence of the lower Mississippi basin. A portion of northern Florida, elevated after the Eocene (or Oligocene, p. 215), constituted an island. On the Pacific coast, the shore line was shifted westward somewhat beyond its present position before the beginning of the Miocene, but as the period advanced, the sea again encroached upon the land, finally reaching the foot of the Sierras. At no time during the period, so far as known, did the sea cover more than narrow borders of the present North American continent. The crustal movements which preceded the Miocene seem to have closed such connection as there was between the Altantic and the Pacific across Central America or the Isthmian region during the Eocene.[2] In the western interior, wide-spread terrestrial aggradation of all phases continued, but the sites of principal deposition differed somewhat from those of the preceding period.

The Atlantic coast.—The Miocene beds of the Atlantic coast are generally unconformable on the Eocene (or Oligocene), but it does not

[1] For general summary of literature on the Neocene (Miocene and Pliocene) prior to 1892, see Dall and Harris, Bull. 84, U. S. Geol. Surv. The bibliography up to 1893 is found in the 18th Ann. Rept. U. S. Geol. Surv., Pt. II (Dall).

[2] Hill, The Geological History of the Isthmus of Panama and Portions of Costa Rica. Reviewed in Jour. of Geol., Vol. VI, p. 661.

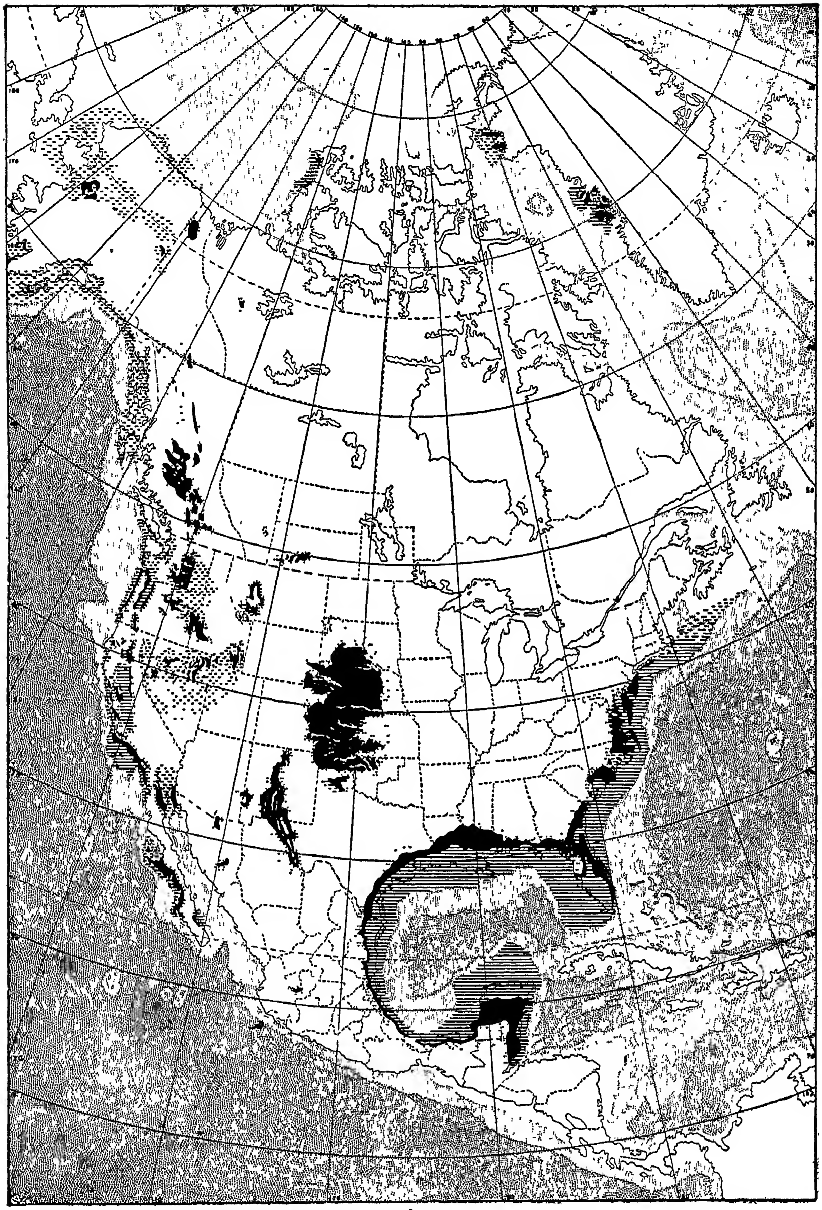


FIG. 442.—Map showing the distribution of the Miocene formations in North America. Conventions as in preceding maps.

appear that the sub-Miocene surface had been deeply eroded before the deposition of the Miocene beds. The slight erosion was probably the result of low altitude, rather than of a short period of exposure, for a considerable interval of time seems to have elapsed between the deposition of the Eocene and that of the Miocene of this province.

The northernmost exposure of the Miocene on the Atlantic coast is on Martha's Vineyard. Between this point and Georgia it appears at the surface interruptedly (Fig. 442). From New Jersey to North Carolina it fails only about the principal bays, where younger formations conceal it. In its surface distribution it sustains the same relation to the Eocene that the latter does to the Cretaceous, though it sometimes overlaps the Eocene, completely concealing it. Like the other formations of the Coastal plain, the Miocene beds dip seaward and are concealed by younger beds before the present shore line is reached. The general relations are indicated by Fig. 380. Even in the belt where the Miocene is mapped as appearing at the surface, it is often thinly covered with younger deposits. The series originally extended inland far beyond its present border, as shown by numerous outliers. In New Jersey,[1] the Miocene series reaches a thickness of 700 feet; in Maryland,[2] about 400 feet, and in North Carolina still less.

The Miocene of the Atlantic coast is for the most part made up of unconsolidated beds of sand, clay, and shell marl. In places, diatomaceous earths (variously known as Richmond earth [from Richmond, Va.], Bermuda earth, Tripoli, infusorial earth, etc.) are found in beds of such thickness (30 or 40 feet [3]) as to be commercially valuable.

Much of the Miocene sand is remarkable for its even grain. It is often aluminous, and has a remarkably soft feel, which has been described as "fluffy." It is often beautifully mottled with delicate colors, and in many places contains small but beautifully smoothed quartz pebbles. Locally, it is cemented into sandstone, and rarely the cementation has gone so far as to convert the sandstone into quartzite.

The Miocene beds of the Atlantic coast are generally grouped under the name *Chesapeake* (or *Yorktown*). They were formerly regarded as Upper Miocene, but the present tendency is to restrict the term Miocene to the Chesapeake, the former Lower Miocene being classed as

[1] Reports of the State Geologist of New Jersey, especially Report of 1892 (Clark).
[2] Clark, Maryland Geol. Surv., Vol. I; also volume on the Miocene, 1904.
[3] Maryland Geol. Surv., vol. on Miocene, p xxx

Oligocene. The fauna of the Chesapeake series has been interpreted to indicate a climate somewhat cooler than that which had preceded, and it has been conjectured that the change was the result of an uplift in the latitude of South Carolina, the axis of the uplift extending seaward sufficiently to divert the Gulf Stream far to the eastward, allowing the cooler waters of the northern coast to affect the coast farther south than before.[1] This suggested explanation hardly seems adequate, and the question may perhaps fairly be raised whether the Miocene fauna of the Southern States does not represent the southward migration of a northern fauna, rather than a notable change of climate. Such a migration might perhaps take place irrespective of climatic change, for the faunas of the north at this time do not appear to indicate any such diversity of climate as now exists.

The Brandon formation.—Besides the marine Miocene beds along the Atlantic coast, there are, at a few points farther inland, lignitic beds which have been thought to belong to the Miocene. They appear to represent accumulations of vegetal matter in marshes more or less distant from the coast. The beds here referred to have been found in Vermont, Pennsylvania, and Georgia, and have been described under the name of the Brandon formation.[2] With them are sometimes associated beds of iron ore. The correlation of these various lignitic and ferruginous beds with one another, and their reference to the Miocene, cannot be regarded as beyond question.[3]

The Gulf coast.—The Miocene of the Gulf coast sustains the same general relations to older formations as that of the Atlantic, except that it is not known to be so generally unconformable on the beds below. Excluding the beds classed as Oligocene, the system has but slight thickness. In Florida, the limestone of the series has locally been changed to lime phosphate.[4] The alteration appears to have been effected through organic matter, especially the animal excrements accumulated about bird, seal, and perhaps other rookeries. The organic matter furnished the phosphoric acid, which, carried down in solution, changed the carbonate of lime to phosphate. The phosphate has been extensively used as a fertilizer for soils. Similar phosphate deposits are found in other places and in other formations.

[1] Dall and Harris, op. cit.

[2] Rept of the State Geol. of Vt., 1903–4; and Clark, Bull. 83, U. S. Geol. Surv. Dana assigns the Brandon formation to the Eocene, Manual of Geology, 4th ed.

[3] Perkins, Bull. Geol. Soc. Am., Vol. XVI.

[4] Penrose, Bull. 46, U. S. Geol. Surv.

Farther west the Miocene is represented by the *Pascagoula* formation (generally a greenish-blue clay) of Alabama [1] and adjacent States, and by the Oakville beds on the coastal slope of Texas.[2] In the latter State there is little Miocene of marine origin exposed, but from borings it is known that marine Miocene beds underlie some parts of the coastal region. Such beds are said to be 1500 feet thick at Galveston. Non-marine beds have extensive development in the northern part of Texas, and will be referred to in connection with the other terrestrial formations of the period. Much of the oil of the Texas-Louisiana coastal plain (Beaumont, Sour Lake, Saratoga, Jennings, etc.) comes from dolomized limestones which overlie Eocene (or Oligocene) clays (Frio). The limestones and associated clastic beds are probably Miocene.[3]

The Pacific coast.—The marine Miocene of the Pacific coast is restricted to a relatively narrow belt. In California, the sea locally invaded the central valley, but the position of the coast line appears to have varied during the course of the period, as a result of crustal movements, sedimentation, and the ejection of igneous matter.

Where the marine Miocene of California (the Monterey series) rests on the Eocene (Tejon), the relation is generally one of unconformity, and where the former overlaps the latter, it often rests on metamorphic rocks. The Monterey series consists of shales, sandstone, and volcanic débris, but varies notably from point to point. Its composition and history in the San Luis region [4] may serve as an instructive illustration of the marine Miocene of the Pacific coast (Fig. 444). Early in the Miocene period, the sea transgressed most of the central and southern parts of the Coast range, but before sedimentation had proceeded far, volcanic activity began and a large amount of pyroclastic rock was extruded from many vents. A notable feature of the sediments of this stage is the abundance of diatomaceous matter with the volcanic ash. In one place, fully a third of a 20 feet thick bed of fine ash, etc., is said to be made up of diatoms. Later, volcanic activity subsided and limestone deposition followed. Still later, organisms secreting silica replaced those secreting lime carbonate, and 4000 feet of shale, largely

[1] Smith, Geol. Surv. of Ala., 1894. See also Reports Geol. Surv. of Texas; also Dall and Harris, loc. cit.

[2] Dumble, Jour. Geol., Vol. II.

[3] Hayes, Bull. 213, U. S. Geol. Surv., p. 346.

[4] Fairbanks, San Luis folio, U. S. Geol. Surv.

of organic origin, were deposited. Such thicknesses of such shale, if their interpretation is correct, imply prodigious lapses of time. The whole system here has a thickness of 5000 to 7000 feet.

In the vicinity of San Francisco, the Monterey series has a thickness of more than 5000 feet, and is composed chiefly of sandstone, but subordinately of bituminous shale.[1] In the interpretation of the great thickness, the considerations previously mentioned should be borne in mind. The sections at other points would show notable variations from those here given. One of the singular features of the Miocene tuffs of the Santa Cruz mountains, near San Francisco, is the occurrence of limestone dikes in them. These dikes are clastic, and the calcareous material of which they are composed is thought to have been forced up into the tuff as ooze from below.[2]

The Miocene is one of the oil-producing horizons of California, and the most important source of bitumen in that State.[3]

The Miocene of western California does not possess the simple structure which characterizes the corresponding beds along the Atlantic and Gulf coasts. Instead of dipping gently to seaward, the strata have been deformed in many places so as to stand at high angles (Figs. 443 and 444). Locally (Mount Diablo range), the beds have been folded, and the folds overturned so that the Chico (p. 160) and Tejon (p. 201) series overlie the Miocene.[4] In the Santa Cruz mountains, the early Miocene beds constitute a part of the metamorphic Pascadero series on which the Later Miocene [5] rests unconformably. The Miocene beds are found in some parts of the Coast Range [6] up to elevations of 2500 feet, and their altitude, position, and stratigraphic relations give some indication of the extent of the deformative movements which have affected this region since the Miocene.

Farther north, considerable parts of western Oregon, including some of the coastal ranges, were under water during the period, and Miocene (Empire) beds a few hundred feet thick, and containing volcanic ash,

[1] Lawson, Science, N. S, Vol. 15, p. 416, 1902.

[2] Haehl and Arnold, Proc. Am. Phil. Soc., Vol. XLIII, p. 16.

[3] Eldridge, Bull. 213, U. S. Geol Surv., p. 306.

[4] Turner, The Geology of Mount Diablo, Bull. Geol. Soc. Am., Vol. 2, 1891.

[5] Ashley, Jour. Geol., Vol III, p 434.

[6] Lawson, Bull. Dept. Geol, Univ. of Cal, No. 1, 1893, and No. 4, 1894; Lawson and Palache, idem, Vol. II, p 364; Ashley, Jour. Geol., Vol. III, p. 434; and Fairbanks, Jour. of Geol., Vol. VI, p. 561.

rest unconformably on the deformed and eroded Eocene[1] (Arago). In British Columbia, there are both clastic and volcanic rocks referred to this period.

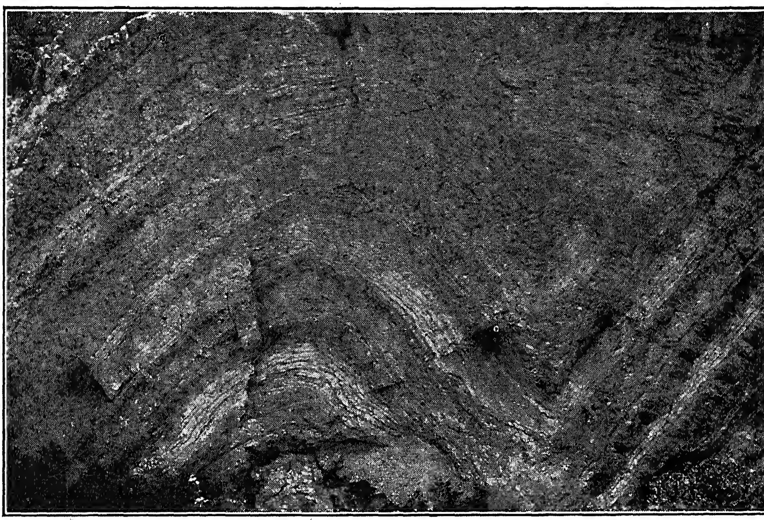


FIG. 443.—Contorted beds of Monterey shale. Mouth of Vaquero Creek, Cal. (Lippincott, U. S. Geol. Surv.)

Non-marine deposits.—While the sea occupied the southern part of the great valley of California (as far north as the Marysville buttes) during at least a part of the Miocene period, it seems not to have overspread the northern part, where contemporaneous deposits of estuarine,

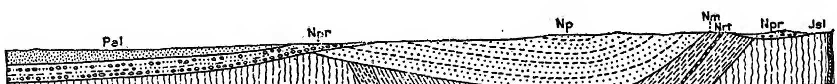


FIG. 444.—Section showing the structure and relations of the Miocene system in the San Luis Obispo region of southern California. *Jsl*, San Luis formation, Jurassic; *Nm*, Monterey shale, Miocene; *Nrt*, rhyolite tuff; *Np*, Pismo formation, Miocene (?); *Npr*, Paso Robles formation, Pliocene; *Pal*, recent alluvium, etc.

lacustrine, and probably subaërial origin (Ione formation) were being made. They consist of the common sorts of clastic sediments, with some coal, iron, etc., and may be continuous, under the later beds

[1] Diller, 17th Ann. Rept. U. S. Geol. Surv., Pt. I, pp. 475–6, and Coos Bay and Port Orford folios, U. S. Geol. Surv.

of the great central valley, with the marine Miocene of western California, though such connection cannot be affirmed. The Ione formation, probably of late Miocene age,[1] is now found at various altitudes ranging up to 4000, or perhaps even to 7000 feet.[2] This has been interpreted as a minimum measure of post-Miocene deformation, on the assumption that the Ione formation was all deposited at or below sea-level. If part of it was fluvial, the above figures are not to be taken as a measure of subsequent deformation.

East of the Ione and the marine Miocene beds of California, auriferous gravels,[3] brought down by streams from the Sierras, were being deposited in the lower courses of the valleys during at least the later part of the Miocene period, and this deposition was continued after the close of the period. These gravels seem to have been deposited on a surface of slight relief, a surface which is interpreted to have been a peneplain developed in the Sierran region in Cretaceous and Early Tertiary (before mid-Miocene) times.[4] The tilting of this plain toward the end of the Miocene seems to have occasioned increased activity of the streams in their upper courses, and the deposition of gravel below. The Sierra mountains are thought to have been at least 4000 feet lower than now when the auriferous gravels were deposited. From some of the gravels of California, thought to be of Miocene age, human relics have been reported,[5] but there seems to be good reason for doubting their authenticity.

During the later part of the period, sedimentary deposits, usually described as lacustrine, are thought to have extended from the central valley of California northward into Oregon, and eastward between the Sierra and the Klamath mountains, into northeastern California, before volcanic extrusions had blocked the Lassen Peak pass. They may connect with the Miocene beds of terrestrial origin known at many points east of the Sierras between the 39th and 41st parallels. Considering these non-marine deposits as lacustrine, it has been thought

[1] Lindgren, Jour. of Geol., Vol. IV, p. 898.

[2] Diller, Jour. of Geol., Vol. II, p. 47.

[3] Whitney, The Auriferous Gravels of the Sierra Nevada of Calif.; Turner, 14th Ann. Rept. U. S. Geol. Surv., 1894; Lindgren, Jour. Geol., Vol. IV, 1896, pp. 881–906; Diller, Jour. of Geol., Vol. II, pp. 32–54. See also folios of the Gold Belt of Calif., U. S. Geol. Surv.

[4] Diller, Jour. of Geol., Vol. II, pp. 33–54.

[5] Whitney, op. cit.

that the waters of an extensive and irregular Miocene (Pah-Ute) [1] lake, or perhaps series of lakes, east of the Sierras, connected westward with the waters in the valley of northern California,[2] and perhaps northward with the John Day basin [3] of Oregon. It is probable, however, that much of this inland Miocene is of fluvial, pluvial, and eolian origin. The sites of some of these deposits seem to have been areas which were subject to erosion during the Eocene, and then to have been so deformed as to become areas of deposition.

The terrestrial Miocene formations (the Truckee Miocene [4] of King) are said to reach a thickness of 4000 feet (King) at some points in the vicinity of the 40th parallel. In general, they are made up of sandstones, conglomerates, volcanic débris, infusorial earths, and fresh-water limestones, overlain by great thicknesses of volcanic tuffs. The John Day series, the upper portion of which is perhaps Miocene, is also thick (said to be 3000 or 4000 feet), and is made up largely of volcanic ash and sand, much of which seems to be eolian.[5] The deformed and eroded John Day formation is overlain by lava, which in turn is covered by a late Miocene formation (Mascall, perhaps =Loup Fork). Miocene beds contemporaneous with the Miocene of the John Day basin occur also in western Oregon and Washington.[6] In the Mount Stuart region of the latter State, 1000 to 2000 feet of basalt (Miocene) is overlain by 1000–1600 feet of sedimentary beds (Ellensburg formation), largely fluvial [7] (Fig. 445).

Other areas of deposition, some of them lakes, existed during the Miocene in Nevada and Montana. In the southwestern part of Nevada, the Miocene beds (Esmeralda formation) described as lacustrine, consist of the usual sorts of clastic rocks, pyroclastic material, and workable coal, the latter showing that the formation is not altogether lacustrine. The formation also carries some sulphur. The remarkable thickness of 14,800 feet (which may include Pliocene beds) is reported

[1] King, Geol. Expl. of the 40th Parallel, Vol. I.

[2] Diller, 14th Ann. Rept., U. S. Geol. Surv.

[3] The earlier John Day beds were Eocene and Oligocene (Dall, loc. cit.), though the later were Miocene.

[4] Op. cit., pp. 412 and 458.

[5] Merriam, Jour. Geol., Vol. IX, p. 71, and Bull. Dept. of Geol., Univ. of Cal., Vol. II, p. 306.

[6] Knowlton, Bull. 204, U. S. Geol. Surv.

[7] Smith, G. O., Mount Stuart, Wash., folio, U S. Geol. Surv.

for this formation.[1] With one exception, the fossil plants of the series are new.[2] In Montana, the Miocene sediments (Bozeman formation, Fig. 446) are described as lacustrine, and are said to have a thickness of nearly or quite 2000 feet. They consist of gravel (conglomerate), sand, clay, limestone, and volcanic dust.[3] In this region some

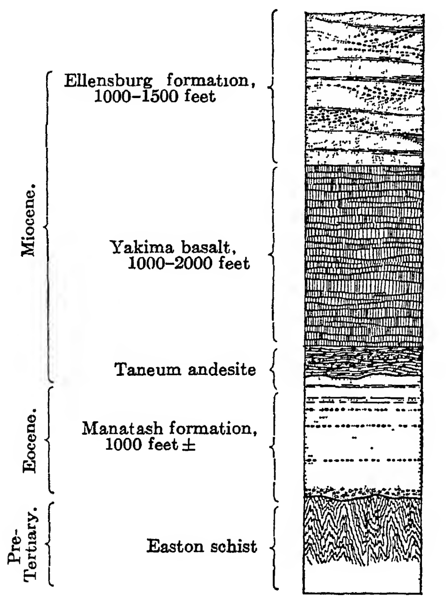


Fig. 445.—Columnar section showing the succession of formations in central Washington. (G. O. Smith, U. S. Geol. Surv.)

of the cones built up by old hot springs, and subsequently buried by clastic sediments, are still preserved.

Farther east, on the western part of the Great plains, the deposition of the White River beds may have continued for a time after the beginning of the Miocene, as indicated by the fauna of the uppermost beds. Late in the Miocene period, aggradation seems to have been renewed in the same general area, and the Loup Fork formation, thin but extensive, was spread out over the western plains. In the early part of this epoch (sometimes called the Deep River stage) the deposits were of slight extent, being apparently restricted to several

[1] Turner, Am. Geol., Vol. 29, p. 268, and 21st Ann. Rept. U. S. Geol. Surv., Pt. II.
[2] Op. cit., p. 219.
[3] Peale, Three Forks folio, U. S. Geol. Surv.

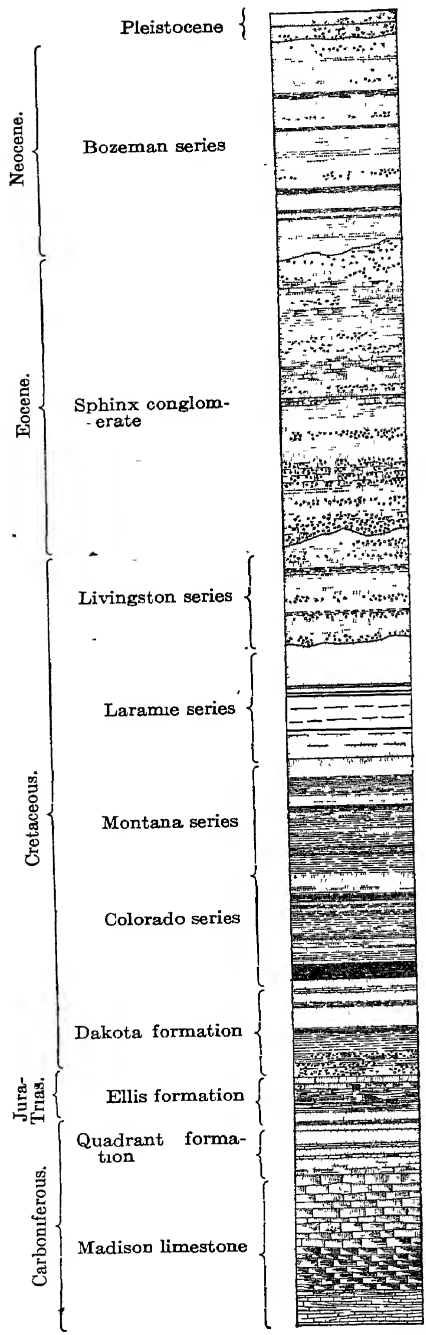


FIG. 446.—Columnar section showing the succession of formations in western Montana. (Peale, U. S. Geol. Surv.)

small areas (lakes?) in southern and central Montana. Later the area of deposition became more extensive, and sediments were spread widely over the area between South Dakota and Mexico. Though the lacustrine and fluvial phases of the formation have not been completely differentiated, it appears that the latter were probably more extensive than the former.[1] To the north, the Loup Fork beds (probably the equivalents of the Arikaree and Gering of western Nebraska [2]) are often unconformable on the deformed and eroded White River

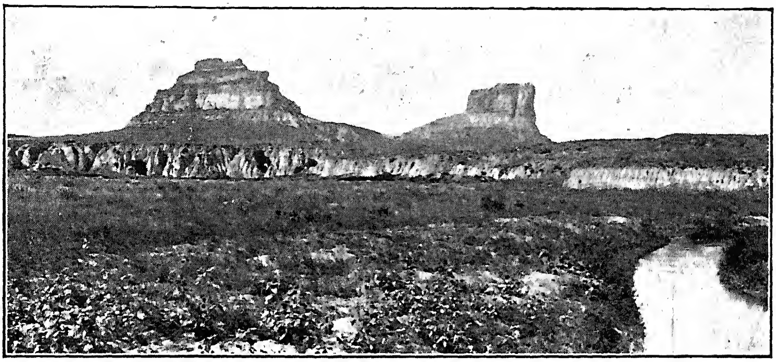


Fig. 447.—Court House and Jail Rocks. Buttes of the Arikaree (Miocene) formation of western Nebraska. (Darton, U. S. Geol. Surv.)

beds, and like the latter have given rise to "bad-land" topography, to striking monuments, buttes, etc. (Figs. 447–449). The Santa Fé (fluvial) marls of New Mexico are correlated with the Loup Fork beds.[3] In Texas, beds of terrestrial sediments are wide-spread in the Llano Estacado region, and have been described under the names Loup Fork and Goodnight, though the Goodnight beds are sometimes regarded as Pliocene.[4]

Terrestrial aggradation was doubtless in progress at many other points in the west, though other considerable formations have not been recognized or not differentiated.[5]

[1] See Haworth, Univ. Geol. Surv. of Kan., Vol. II, p. 281.

[2] Darton, U. S. Geol. Surv., 19th Ann., Pt. IV, and Camp Clarke and Scott's Bluff, Neb. folios, U. S. Geol. Surv.

[3] Johnson, D. W., Geology of the Cerillos Hills, N. M., Sch. of Mines Quarterly, Vol. XXIV, p. 313, 1903. Bibliography given.

[4] Scott, Introduction to Geology, p. 518.

[5] The relations of the Miocene are shown (under the name of Neocene) on various

Lake and other terrestrial deposits, largely of volcanic material, are known north of the United States, especially in that part of British Columbia[1] between the Coast and Gold ranges. The volcanic centers seem to have been numerous, and along the eastern base of

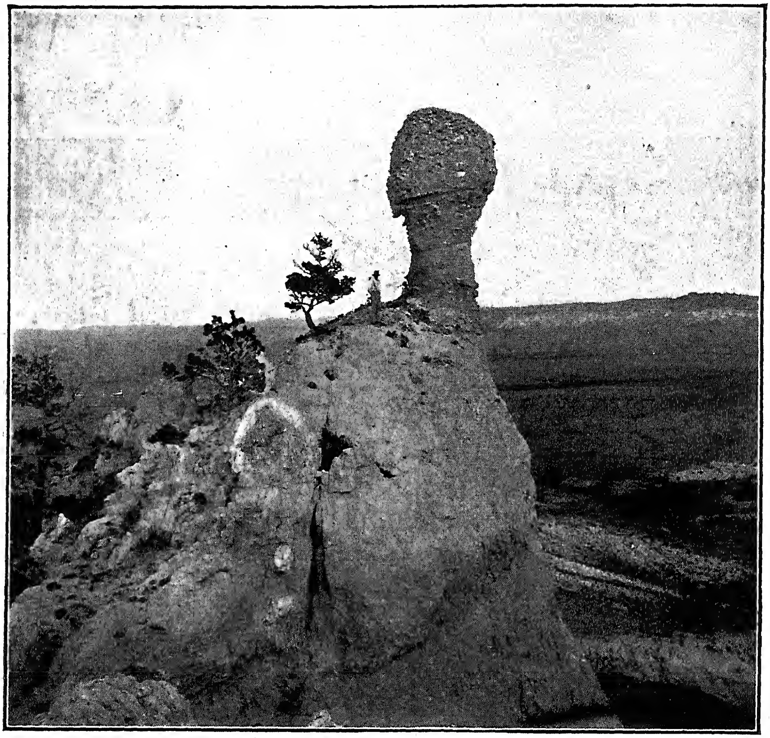


FIG. 448.—Smokestack Rock. Conglomerate in the Arikaree formation of western Nebraska. (Darton, U. S. Geol. Surv.)

the former range. Miocene deposits are known as far north as the Francis River, and also on the Porcupine branch of the Yukon; but erosion rather than deposition was the dominant process in Alaska, so far as present data show.

Igneous activity during the Miocene.—The wide-spread igneous activity which began with the close of the Cretaceous and continued,

folios of the U. S. Geol. Surv. Both sedimentary and igneous formations are represented.

[1] Dawson, G. M., Trans. Royal Soc. of Canada, 1890.

at least intermittently, through the Eocene, made itself felt also in the Miocene, and perhaps reached its maximum toward the end of that period. The frequent references in preceding pages to igneous materials in the sedimentary formations of the system give some idea of the extent of Miocene vulcanism. The eruptions were from fissures as well as from volcanoes, and extensive sheets of lava as

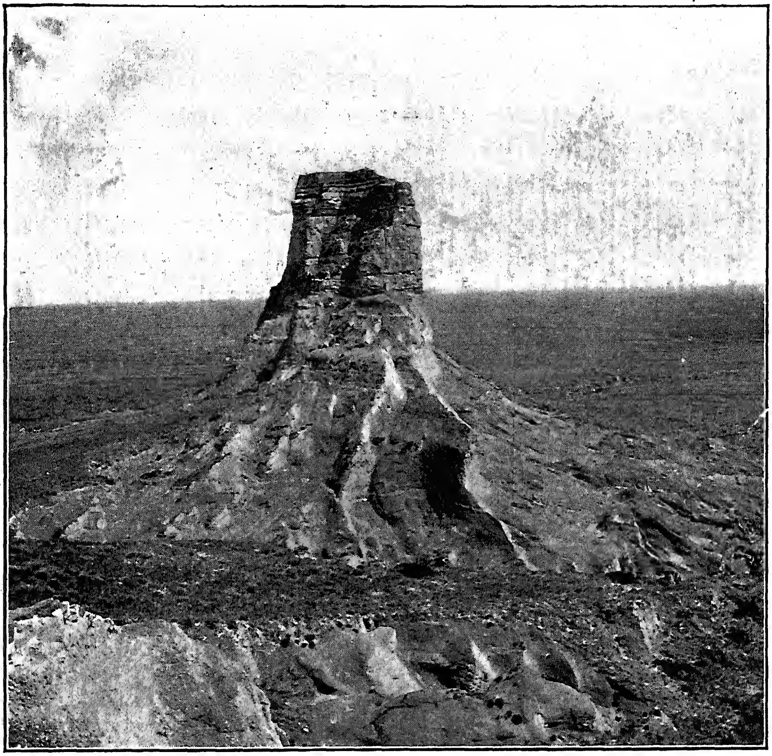


FIG. 449.—Monument of Gering (Miocene) sandstone over Brule (Eocene) clay, western Nebraska. (Darton, U. S. Geol. Surv.)

well as volcanic cones were formed, and intrusions as well as extrusions were of frequent occurrence. Evidences of volcanic activity during this period are found in nearly or quite every State west of the Rocky mountains. Among other centers of igneous activity may be mentioned the basin of the Columbia [1] and the Yellowstone National

[1] Landes, Wash. Geol. Surv., Vol. II, and Smith, G. O., Ellensburg folio, U. S. Geol. Surv.

Park,[1] where evidences of Miocene volcanic activity are to be seen on all hands. Locally,[2] forests were buried by the volcanic ejecta,

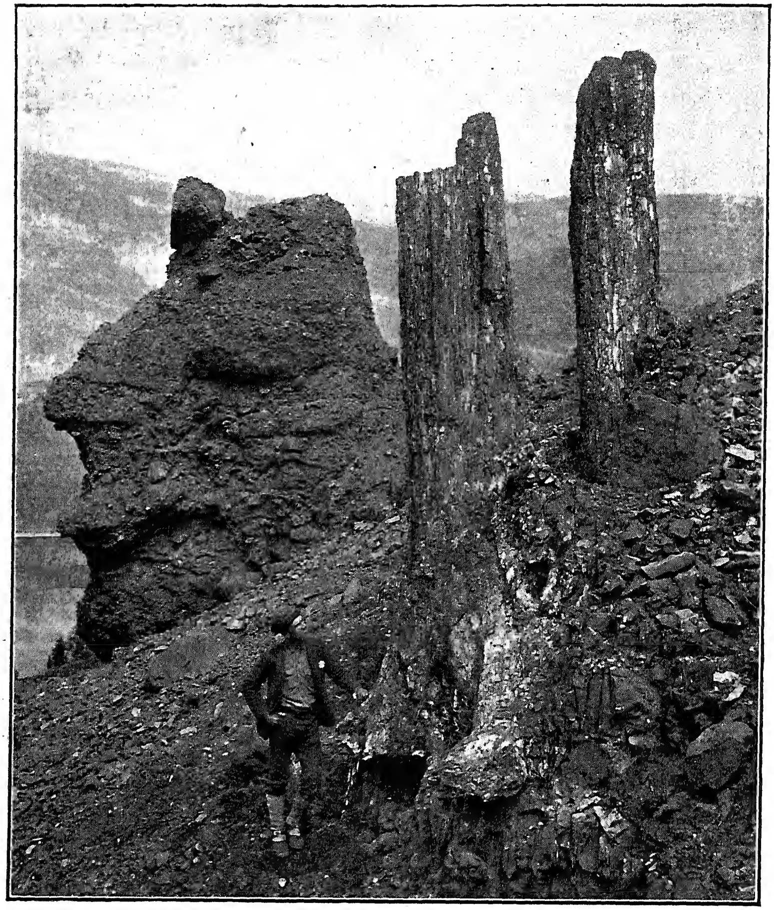


FIG. 450.—Petrified tree-trunks, Yellowstone National Park. (Iddings, U. S. Geol. Surv.)

and in favorable situations their trunks were petrified (Fig. 450). Great areas of the sedimentary beds of the period are concealed by

[1] See western folios, U. S. Geol. Surv., notably the Yellowstone National Park folio. Most of the folios showing Neocene formations show volcanic rocks of Neocene age.

[2] Yellowstone National Park folio.

the lavas, but the extrusions were by no means confined to the areas where Miocene sedimentation had been in progress.

While igneous activity has been in progress interruptedly since the earliest known times, the record of few periods of geological history shows such extraordinary extrusions of lava as those of the Tertiary. The exact stage of the Tertiary at which the great lava sheets of the west were extruded has not been determined in all cases; but the lavas of at least a considerable part of 200,000 or 300,000 square miles of lava-covered country in the western part of the United States

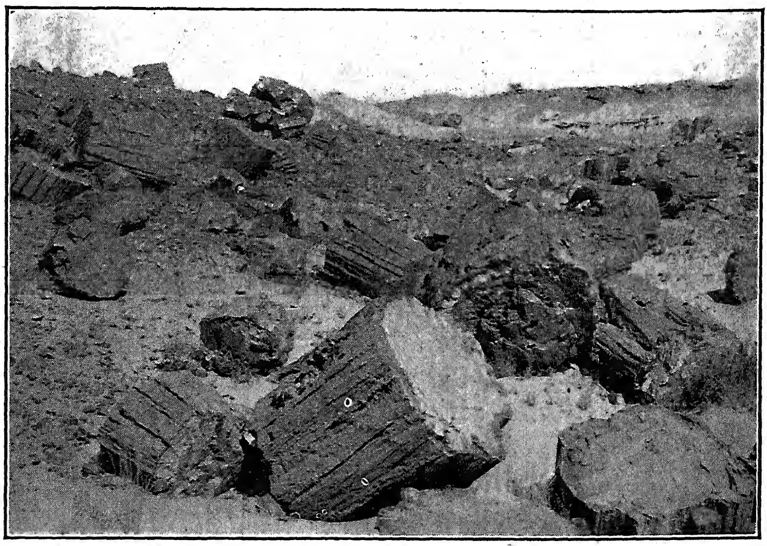


FIG. 451.—Sections of petrified logs, near Holbrook, Ariz. Age of beds not known.

issued during the Miocene period, or during the time of crustal deformation which brought it to a close.

The volcanic activity of the time was not restricted to the Cordilleran system, but affected also the Antillean system of Central America and the West Indies,[1] and the Andean system of South America.

Close of the Miocene.—During the Miocene, there appears to have been more or less crustal movement throughout the Cordilleran region. Slow warpings of the surface seem to have been in progress, while

[1] Hill, Geology of Jamaica. Reviewed in Jour. of Geol., Vol. VII.

faulting, vulcanism, and gradation all produced changes in the physiography of the west. Locally, as in the Santa Cruz mountains of California, there were pronounced orogenic movements [1] in the course of the period, but toward its close crustal movements seem to have been general. At this time pronounced deformative movements took place in the coastal regions of Oregon [2] and California, tilting and folding the Miocene and older formations. The principal growth of the existing Coast ranges of both these States, and of the San Fernando mountains of California are usually assigned to this time.[3] The orogenic movements in the Mount Diablo region have already been referred to. The Cascade mountains of Washington also had notable growth at this time.[4]

Similar movements appear to have been wide-spread throughout the Cordilleran system, sometimes resulting in the deformation of strata heretofore horizontal, but more commonly affecting formations and areas which had suffered deformation at some earlier time. In California, the Sierra peneplain, developed during the Cretaceous, Eocene, and early Miocene periods, was deformed by being tilted up on the east, increasing the grade of the westward flowing streams. This deformation appears to have begun before the close of the Miocene, and to have furnished the conditions necessary for the deposition of the late Miocene auriferous gravels.[5] Remnants of this old plain are now 600 to 1900 feet above sea-level at the head of Sacramento valley, and several thousand feet high in the main range. In northern California, the deformation was such as to emphasize the central valley of the State. Since that time, too, there has been faulting to the extent of 3000 feet on the east side of the northern Sierras.[6] Deformation and faulting at the close of the Miocene seem also to have been wide-spread and pronounced in the Great Basin region,[7] and to have affected some parts of Colorado.[8]

[1] Ashley, Jour. Geol., Vol III, p. 434; Whitney, Geol. of California, I.

[2] Diller, 17th Ann. Rept. U. S. Geol. Surv.

[3] Ashley, op. cit.

[4] Willis, Professional Paper 19, U. S. Geol. Surv.

[5] Diller, Jour. Geol., Vol. II, p. 30, and Lindgren, Jour. of Geol., Vol. IV, p. 881 et seq.

[6] Diller, 14th Ann. Rept., U. S. Geol. Surv.

[7] King, op. cit., p. 414, and Dutton, op. cit., p. 226.

[8] Walsenburg folio, U. S. Geol. Surv.

In addition to the more distinctly deformative movements, body movements and block movements resulting in the increased altitude of the land throughout much of the western half of the continent were in progress at this time. It appears to have been at about this time that the plateau region of Arizona and southern Utah, a region which prolonged erosion had reduced to a peneplain, was uplifted so as to permit the beginning of the excavation of the Grand Canyon of the Colorado.[1] Other regions were depressed relative to their surroundings, and the differentiation of levels was often by faulting along planes of earlier displacement. It appears that the later part of the Miocene was the time when the greater relief features of the rugged west, as they now exist, were initiated. The great relief features of earlier times, for such there had been, appear to have lost their greatness before the end of the Miocene.

After the movements of the late Miocene had been accomplished, it is probable that the western part of the continent had a topography comparable, in its relief, to that of the present, though by no means in correspondence with it. The details, and even many of the larger features, of the present topography are of still later origin. Subsequent changes have been the result of (1) deformation, largely without notable folding, (2) faulting, (3) the extrusion of lava, and (4) extensive degradation and aggradation, by running water, by ice, and by wind.

Volcanic activity and faulting, both on a great scale, seem to have attended the deformative movements of the closing stages of the Miocene. The lavas on the plateaus north of the Grand Canyon have been referred to the close of the Miocene, and the Tertiary volcanic activity of the Basin region reached its maximum at this time.[2] Though direct connection between intensity of movement and vigor of volcanic activity has not been established, the connection of the extensive igneous eruptions with the crustal warping and breaking, can hardly be fortuitous. How far the one was cause and the other effect, how far they were mutually cause and effect, and how far they were effects of a common cause, are questions to which no decisive answer can now be given.

[1] Dutton, Mono. II, U. S. Geol. Surv.; see also Davis, Am. Jour. Sci., 4th series, Vol. X, p. 250.

[2] King, op. cit., pp. 414–415.

In the eastern part of the continent, the geographic changes were less considerable, though the Atlantic and Gulf regions seem to have emerged, transferring the coast-line to some such position as it has to-day. The island in northern Florida which came into existence near the close of the Eocene was joined to the mainland at the end of the Miocene, thus bringing the peninsula of Florida into existence.

The foregoing references of deformative movements to the close of the Miocene are in harmony with prevailing classifications, but are not in consonance with the principle of time-division previously set forth, in which a dynamic movement is made the initiating event of a new period. According to this principle, the deformative movements here referred to the closing stage of the Miocene, should be transferred to the opening stage of the Pliocene, or regarded as a transition to it.

Foreign.

Europe.—In Europe, the relations of sea and land were in general much as in the Early Tertiary. The area of the sea was much restricted in northern Europe, and perhaps more extended in the southern part of the continent than it had been during the Oligocene. Non-marine formations have much representation in this, as in most other post-Paleozoic systems. Some of the non-marine formations are of brackish-water origin, and some of fresh.

The marine beds occur chiefly along the Atlantic and Mediterranean coasts. At the north, there was a great bay in the northwestern part of Germany, including most of Holland and a part of Belgium, but the beds deposited in it are mostly buried under a heavy body of glacial drift. Elsewhere in Germany, except at the extreme south, the somewhat wide-spread Miocene deposits are of non-marine origin. They include coal and tuff, besides the commoner clastic sediments. In southern Germany (Alpine region), the Miocene Molasse (marine below and non-marine above) overlies the Oligocene portion of the same series (p. 250), and is continued into Switzerland. The oceanic connection of the waters in which the marine beds were deposited was to the south. Thick conglomerates (3900–5900 feet) of Early and Middle Miocene age are found along the north base of the Alps (Rigi). Their materials came in part from formations which are still visible, but in part from formations which do not now appear at the

surface.[1] Such thick beds of coarse sediment tell something of the relief of the Alpine region at this time.

A shallow epicontinental sea covered a part of Belgium and France, overspreading the plains of the Loire and Garonne. From the basin of the latter, there may have been a sea connection with the Mediterranean along the northern base of the Pyrenees. Parts of the Iberian peninsula also, were submerged.

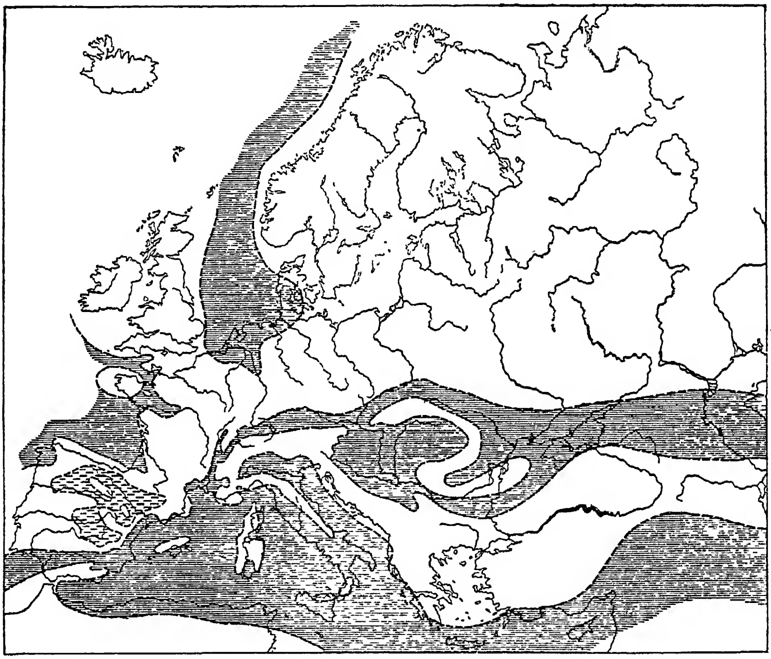


Fig. 452.—Sketch-map of Europe in the Miocene period (Helvetian). The continuous lines are the areas of marine deposition; the broken lines areas of non-marine deposits. (After De Lapparent.)

The sea covered much of southern Europe, sending an arm up the valley of the Rhone as far as Mayence, but the water at the head of this basin was changed from marine to brackish in the course of the period. From this bay a strait ran eastward between the Alps and the present Danube, and expanded in the basin of Vienna, one of the most important areas of the Miocene system. An arm of the

[1] Geikie, Text-book, 4th ed., p. 1270.

sea extended thence through Moravia, and spread far and wide among the islands of southeastern Europe, over the regions of the Black and Caspian Seas.[1] These great inland seas may be looked upon as the relics of the Tertiary extension of the sea across southern Europe.

From the distribution of Miocene strata it is inferred that southern Europe was an extensive archipelago, the plateau of Spain, parts of Pyrenees, the Alps, and the Carpathian mountains, and portions of adjacent lands, being islands. Malta and Sicily had probably not appeared, as both are composed chiefly of marine Miocene formations. The borders of the sea were marked by peninsular headlands giving it notable irregularity. The strait of Gibraltar is thought to have been closed, and southern Spain joined to Africa; but there were perhaps straits across Spain, as across southern France, connecting the Atlantic with the southern sea. To the east, the sea was expanded far beyond the limits of the present Mediterranean, but without connection with the Indian ocean. Though extensive areas of Europe which are now land were then submerged, some areas which are now submerged, e.g. the eastern part of the Adriatic, are thought to have been land at that time.

Late in the Miocene period, there was a notable withdrawal of the sea from the land, for many of the late Miocene deposits were laid down in brackish and fresh waters, over marine beds referred to the earlier part of the period. Thus the connection of the Vienna basin with the Mediterranean sea, *via* the Rhone valley, was closed, or greatly restricted, before the end of the period, and bodies of brackish and fresh water came into existence where the sea had been. Well-defined brackish-water faunas are developed in some places.

The Miocene formations include all the common sorts of sedimentary rocks common to marine and non-marine deposits. The latter include not a little limestone of fresh-water origin, made partly from the secretions of algæ. As was natural, too, under the conditions of sedimentation, the limestones of certain localities are made up almost wholly of the secretions of a single type of life. Thus in the Vienna basin, the limestone is made up in some places chiefly of coral, in others of the shells of gastropods, in others of foraminiferal shells, in others of the secretions of algæ, etc. The system has great development in Italy, where it attains a thickness of nearly 6000 feet.

[1] Geikie, Text-book of Geology, 4th ed., p. 1261.

In spite of the wide sway of the southern sea of Europe, the Miocene formations do not appear at the surface in great areas, though found in all countries bordering the Mediterranean, both in Europe and Africa. In most of these countries, the lower formations are of marine origin, and the upper of brackish- or fresh-water origin.

About the Dardanelles, such beds contain petroleum and bitu-

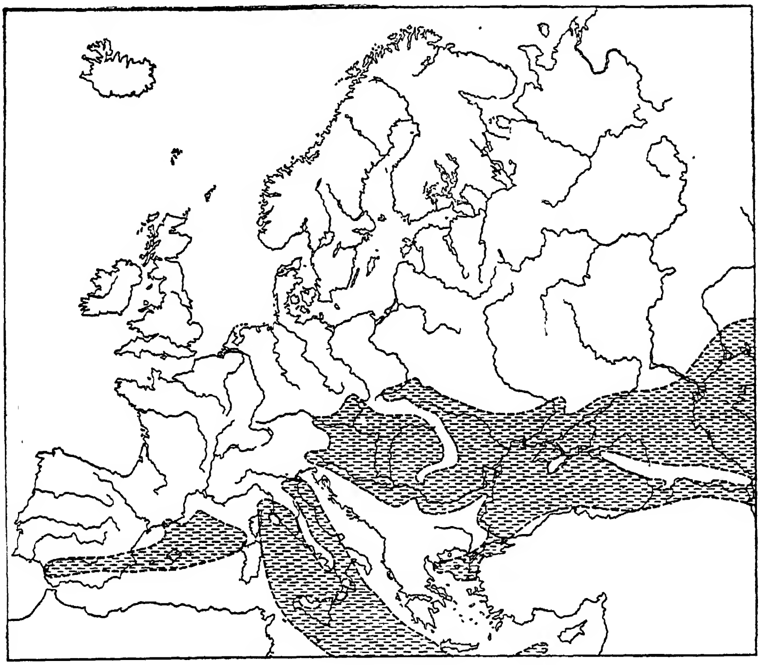


FIG. 453.—Sketch-map showing area of non-marine deposits of the closing stage (Sarmatian) of the Miocene. (After De Lapparent.)

men.[1] In Africa, Miocene formations occur in Algeria and in Lower Egypt, but not in Upper Egypt. They also occur in Syria, but not in Arabia and Persia, showing that the water connection between the Mediterranean and Indian ocean regions had come to an end. The Gulf of Suez is thought to have been a Mediterranean bay at this time.[2]

Close of the Miocene in Europe.—In Europe as in America con-

[1] English, Q. J. G. S., 1904, pp 255–260.
[2] Hume, Geol. Mag., 1904, pp. 250–252.

siderable disturbances occurred in the later part of the Miocene period, and at its close. Before the end of the period the Alps had had a period of growth, usually placed at the close of the Lower Miocene. This date is fixed by the fact that the Lower Miocene beds on the Alpine side of the Vienna basin are upturned, while the Upper Miocene beds remain nearly horizontal. This is hardly to be regarded as conclusive evidence that other mountains which were in process of development during the Miocene had their principal growth at the same time, for about other parts of the Vienna basin the Upper Miocene and even later beds are deformed. The Apennines and other mountains of southern Europe were also in development during the later Miocene. In the Caucasus mountains, Miocene beds occur up to heights of 2000 meters. It will be seen, therefore, that deformative movements, resulting in the formation of great mountain systems, were in progress in southern Europe, as well as in the western part of America, during the later part of the Miocene period. Mountain-making movements were apparently in progress in the Himalayan region also, and perhaps in other parts of Asia. As in America, too, wide-spread movements which were not notably deformative attended the growth of the mountains, with the result that the sea which had overspread southern Europe was greatly restricted, though not reduced to its present size. Igneous activity appears to have attended the movements of the time, but not on so great a scale as in North America.

Other continents.—The Miocene of Asia has not been generally separated from the other Tertiary formations, but it is known to exist in India [1] (Sind), Burma,[2] and Japan,[3] where the Tertiary (Miocene?) contains petroleum and metaliferous veins, and in some other parts of northeastern Asia. It is also found in Java, where it has a rich fauna.[4] The beds commonly referred to this system contain both marine and terrestrial formations.

Australia is rich in Miocene beds, some of which are of marine, some of lacustrine, and some of fluvial origin. Toward the end of

[1] Oldham, Geol. of India.

[2] Pal. India, New Series, I, 1901.

[3] Geology of Japan, Imp. Geol. Surv, 1902.

[4] Martin, Die Tertiarschichten auf Java, 1879-80. See also Zeitschr. d. d. geol. Gesell., 1900.

the period, sheets of basalt were poured out over the sedimentary formations. In New Zealand [1] also, the system is well developed on both islands. It includes both marine and non-marine beds, and among the latter, coal. The fauna is distinguished by the great size of some of its molluscan shells. Both the flora and fauna have a tropical aspect. The fruit of the palm has been found as far south as latitude 45°. Igneous rocks are associated with the sedimentary. The beds are found up to heights of 2500 to 4000 feet, giving some clue to the extent of post-Miocene crustal deformation. Miocene is found, with other Tertiary formations, in Borneo and in the Philippines.[2]

In South America, Miocene beds probably occur on the western coast, and are known to have extensive development on the eastern plains of the southern part of the continent,[3] where the distinction between the Upper Oligocene and the Miocene is not sharp. The lower part of the Oligocene-Miocene series (Patagonian beds) is marine, while the upper part (Santa Cruz) is of fresh-water origin. A striking feature of the faunas of this region is their similarity to the Miocene and later faunas of Australia and New Zealand. This relationship has caused speculation as to an Antarctic continent connecting these regions.[4] Miocene is probably present also in northern Chili.[5]

Arctic latitudes and climate.—Miocene beds are somewhat widely distributed in high latitudes. They are found in Spitzbergen (Lat. 78°), in Greenland (Lat. 70°), in Grinnell Land (Lat. 81° 45′), and at other points in the Arctic regions. In all these places the formations seem to have been largely of terrestrial origin, and the fossil floras indicate a warm temperate climate. Forty-six of the 137 species of plants found in North Greenland [6] (Lat. 70° and less), including species of sequoia and magnolia, are also found in central Europe. The floras of Spitzbergen and Grinnell Land were hardly less luxuriant, or less

[1] Geikie, Text-book of Geol., 4th ed., p. 1274 from Murray and Hector).

[2] Becker, 21st Ann. Rept., U. S. Geol. Surv., Pt. III, p. 548 et seq.

[3] Hatcher, Sedimentary Rocks of Southern Patagonia, Am. Jour. of Science, Vol IX, 1900; and Ortmann, Princeton Univ. Repts. of Expedition to Patagonia, Vol. IV, Pt. II.

[4] Ortmann, op. cit.

[5] Möricke and Steinmann, N. Jahrbuch f. Min., etc., Beilagebd., X, p. 533, 1896.

[6] Heer, Flora Fossilis Arctica, 1868–83. Also Q. J. G. S., 1878, p. 66, and Nordenskjöld, Geol. Mag., 1876, p. 257.

strongly in contrast with the floras of the same region at the present time. Curiously enough the Miocene plants of Alaska, Kamschatka, and Japan indicate a climate cooler than that of the higher latitudes. It seems probable that this apparent discrepancy is the result of imperfect correlation, the fossils indicating these inharmonious conditions not being contemporaneous. If this is the explanation of the apparent anomaly, the subtropical floras of the high latitudes are probably earlier than the other floras with which they have been compared. In any case, the existence of warm temperate conditions in such high latitudes in such recent times is remarkable, especially when it is remembered that extensive ice sheets were soon (geologically speaking) to affect not only these regions, but regions much farther south.

It is worthy of emphasis that throughout all lands where the Miocene system is known, terrestrial aggradation seems to have been one of the leading features of the period. Terrestrial aggradation implies still greater terrestrial degradation, and relatively great relief. The necessary relief seems to have been the result of the crustal movements which brought the Eocene period to a close.

The Life of the Miocene.

The Land Plants.

The flora of the Miocene in the mid-latitudes differed from that of the Oligocene chiefly in the gradual disappearance of the characteristic subtropical types, and in an increased proportion of deciduous forms, especially of those that are now present in the same regions. This is particularly true of North America, where the flora came to resemble that which to-day lives in somewhat lower latitudes, and is indeed its successor. The flora of Europe bore a similar "American" aspect, but this it has not retained in an equal degree. This is attributed by Zeiller to the barrier to southern migration interposed by the Mediterranean during the ice invasions of Pleistocene times, a barrier which prevented the plants from escaping southward, and led to the destruction of many species which subsequent migration from other regions did not restore. In Europe there were also, in the early part of the period, not a few species now found in India and Australia, giving, as in the previous period, an "Australian" sub-aspect to the flora. A very important feature in North America was an increase in the

grasses, which in turn influenced the evolution of the mammals in the lines already pointed out.

How far the gradual removal to the south of the forms now regarded as tropical or subtropical, and the concentration at the north of the forms that now characterize those latitudes, was the result of a natural differentiation and segregation of the previously mixed forms, and how far the result of a progressive differentiation of climate, it is perhaps unsafe to say; it has usually been attributed to the latter. It has been customary to interpret the climatic implications of the Tertiary floras by the southern forms, such as the palms, magnolias, figs, etc., and to ignore the northern forms, poplars, willows, etc. For this there are apparently some good reasons, but it is not clear that they are conclusive.

According to Heer,[1] there were Miocene forests in high latitudes (Nova Zembla, Spitzbergen, Iceland, Greenland, Grinnell Land, Banks Land, the mouth of the Mackenzie, and Alaska) which contained pines, cypresses, birches, maples, walnuts, poplars, elms, oaks, lindens, willows, hazels, and even magnolias and tulip-trees. Question has however been raised as to the period to which these belong, and as the areas are all isolated, stratigraphical tracing is impracticable. It seems not impossible that they were Eocene. When, as in a case like this, there is ground to suspect that faunas and floras are forced by climatic changes to migrate rather rapidly in latitude, the basis of correlation by fossils is disturbed, for the existence of the same faunas and floras in different latitudes does not prove contemporaneity; it may only mean successive occupancy by forced migration. Exact correlations therefore become very difficult. But the occurrence of these plants in so high latitudes in either the Eocene or Miocene is sufficiently remarkable.

The Land Animals.

The earlier fauna.—The early Miocene of North America (John Day epoch) was separated by a long interval from the late Miocene (Loup Fork epoch) and this gave a marked distinctness to the faunas of the two epochs. The earlier resembled the Oligocene (White River) fauna in general aspect, but most of the mammalian genera, and nearly

[1] Flora Fossilis Arctica, Vol. I, p. 161.

all the species were new and more modern in type. The primitive carnivores, the creodonts, had disappeared and their places were taken by true carnivores. These were chiefly of the cat and dog families, with a few mustelines. Three of the short-lived side branches of the odd-toed ungulates had dropped away, the titanotheres, the upland running rhinoceros, and the aquatic rhinoceros, reducing the perissodactyls essentially to their three persistent lines, the horse, the tapir, and the lowland rhinoceros. A straggling lophiodont and an occasional doubtful form represented the last serious efforts of the odd-toed tribe in side lines. It seems to have found its place by its previous trials, and thereafter developed consistently along its three most successful lines. A similar remark may be made of the even-toed branch from which the anthracotheres, protocerases, xiphodonts (European), cænotheres, and anoplotheres disappeared, and the evolution settled down into the modern lines. The elotheres lingered through the early epoch, and the oreodons through the whole period, being very abundant during the early part. Peccaries and camels flourished, and the rodents were well deployed, including squirrels, beavers, gophers, rabbits, and lemmings.

The later fauna, the elephants.—In the late Miocene (Loup Fork) the fauna was broader in type. The most notable addition in North America was the proboscidians. It is now practically demonstrated [1] that the elephant family originated in Africa, migrated later to Eurasia, thence to North America and later to South America. The elephants reached North America in the late Miocene, and South America in the Pliocene. They were first known in Europe in the lowest Miocene (Burdigalian of France), while primitive proboscidians lived in Egypt at least as early as the Middle Eocene. This confirms the anticipations of Stehlin,[2] Osborn,[3] and others, that the point of dispersion of the *Proboscidea* and some other groups would be found in Africa. The Eocene forms thus far found in Egypt are *Moeritherium, Barytherium, Palæomastodon,* and perhaps *Arsinöitherium,* an aberrant type of doubtful

[1] C. W. Andrews and Hugh J. L. Beadnell, New Mammals from the Upper Eocene of Egypt, Geol. Surv. of Egypt, 1902; C. W. Andrews, Evolution of Proboscidea, Phil. Trans., Roy. Soc. Lond., 1903.

[2] Ueber die Geschichte des Suiden-Gebisses, II. Thiel; Abh. d. Schweiz, Pal. Gesell., Vol. 27, 1900, p. 477.

[3] Correlation between Tertiary Mammal Horizons of Europe and America, Ann. N. Y. Acad. Sci., Vol. XIII, 1900, pp. 1–72.

classification. The forms found in Eurasia in the Miocene are *Dinotherium* and *Tetrabelodon;* those found in the Upper Miocene in North America are *Tetrabelodon* and *Dibelodon.* The *Dinotherium,* which was distinguished by downward curved tusks in the lower jaw, seems never to have reached America. This, together with the simplicity of the teeth of the American *Tetrabelodon,* has suggested that the latter may have reached America by some other than the European route, perhaps *via* eastern Asia.

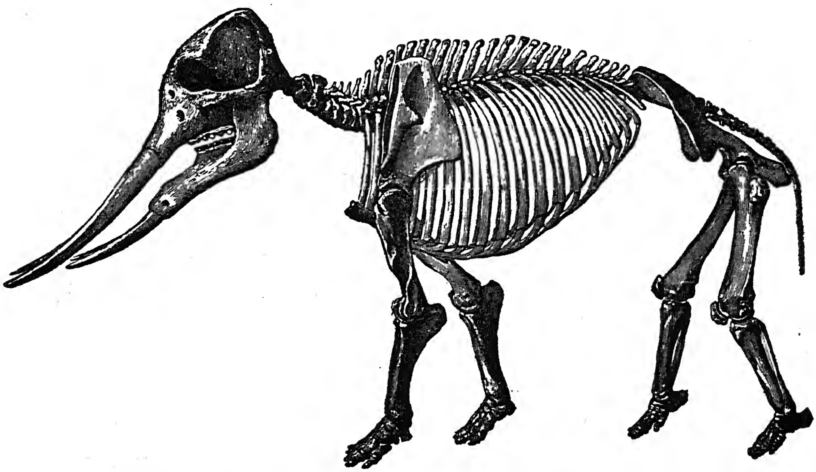


Fig. 454.—A Miocene Mastodon, *Tetrabelodon angustidens* Cuvier. (Restoration by Gaudry.)

The immigration of the ruminants.—Much more important in ulterior results was the immigration of the modern ruminants. Certain branches of the ruminants had been represented previously by the *Tragulidæ, Camelidæ,* and perhaps other groups now extinct, but the great ruminant group that later formed so important a part of the fauna does not seem to have been derived from these, but to have immigrated from Eurasia. They are first recorded in the Loup Fork beds. The first immigrants belonged to the deer and ox families. The earliest known deer (not including *Protoceras*) are first known in Europe. They were hornless, as are their surviving relatives in Asia, the musk-deer and the Chinese water-deer.[1] By the middle of the Miocene period certain male forms had acquired small two-pronged deciduous antlers, fixed on long bone pedicles. About the close of

[1] Vert. Pal., Woodward, p. 365.

the period, three or four prongs were added, and in the Pliocene the antlers were variously branched and the pedicles were shortened to insignificance, as in most living deer. This historical evolution of the antlers is reproduced in the individual history of the modern male deer. Born hornless, he acquires in successive years the single, the bifurcate, and the more and more complexly branched antlers that mark the history of the race. It was in the bifurcating stage that the deer appeared in America, its antlers being simple and small, but variable. The skeletons imply lightness and speed, but a less complete adaptation to celerity than was attained later.

There is some doubt as to the precise stage to which the remains of bison found in Nebraska and Kansas are to be assigned. They have usually been referred to the Lower Pliocene, but Matthew assigns them to the Upper Miocene, while Williston refers them to the early Pleistocene.[1] The earliest known bisons on the Eurasian continent have been found in the Siwalik formation of India, which is regarded as Lower Pliocene.

The camels, oreodons, and peccaries.—Besides the new families of artiodactyls, three of the previous ones continued to flourish, the camels, the oreodons, and the peccaries. Fifteen species of camels have been identified from the Loup Fork formation, belonging to the genera *Procamelus*, *Protolabis*, *Miolabis*, *Oxydactylus*, and *Pliauchenia*. The more primitive genera of the White River and John Day epochs had disappeared. The more robust *Procamelus* and its allies of the Loup Fork epoch quite distinctly foreshadowed the true camels which were later to go to Asia, while the *Pliauchenia* foreshadowed the llamas, which were later to go to South America; but the whole family seems yet to have been confined to North America. The oreodons, though destined to become extinct at the close of the period, were represented by 18 American species. They appear thus not to have dwindled away but to have gone out suddenly, in the geological sense, not unlikely from the attacks of some new carnivore. They appear never to have migrated from North America. The peccaries do not seem to have been specially abundant.

The evolution of the horse.—It was a great epoch in the evolution of the horse, *Anchippus*, *Protohippus*, *Pliohippus* (*Merychippus*), *Hipparion*,

[1] Bull. Am. Mus. Nat. Hist., XII, 1899, p. 74.

and other genera flourished and deployed into forty or more species. They were still three-toed, but the two lateral toes were much reduced and did not usually touch the ground, while the central one was strengthened and bore all the weight. A large group of structural features were being modified, concurrently with the feet, to fit the

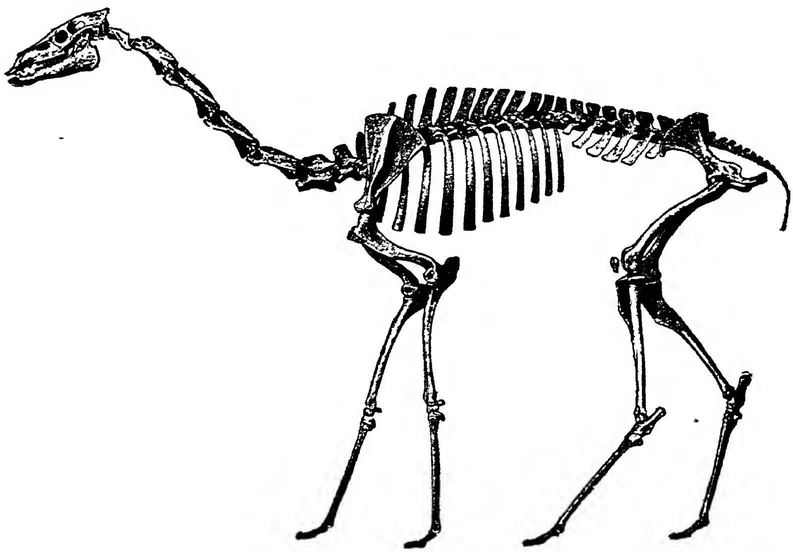


FIG. 455.—An American Miocene Camel, *Oxydactylus longipes* Peterson, from the Loup Fork beds of Nebraska. (After Peterson.)

evolving horse to the open dry plains and their grassy food (Fig. 456). The elimination of the side toes, the lengthening of the limbs, the change of the joints to the "pulley-wheel" type, the concentration of the limb muscles near the body to reduce the weight of the parts most moved, and the consolidation of the leg bones, were modifications in the interest of combined speed and strength. A corresponding elongation of head and neck was necessary to reach the ground. The front teeth were reduced to chisel-like, cropping forms, somewhat resembling those of the rodents, while the molars evolved a tortuous distribution of the enamel so flanked by dentine and cement that the differences of wear gave rise to ridges of enamel suited to grinding, and protected against breaking by supporting dentine and cement on either side. The teeth were also gradually elongated to provide

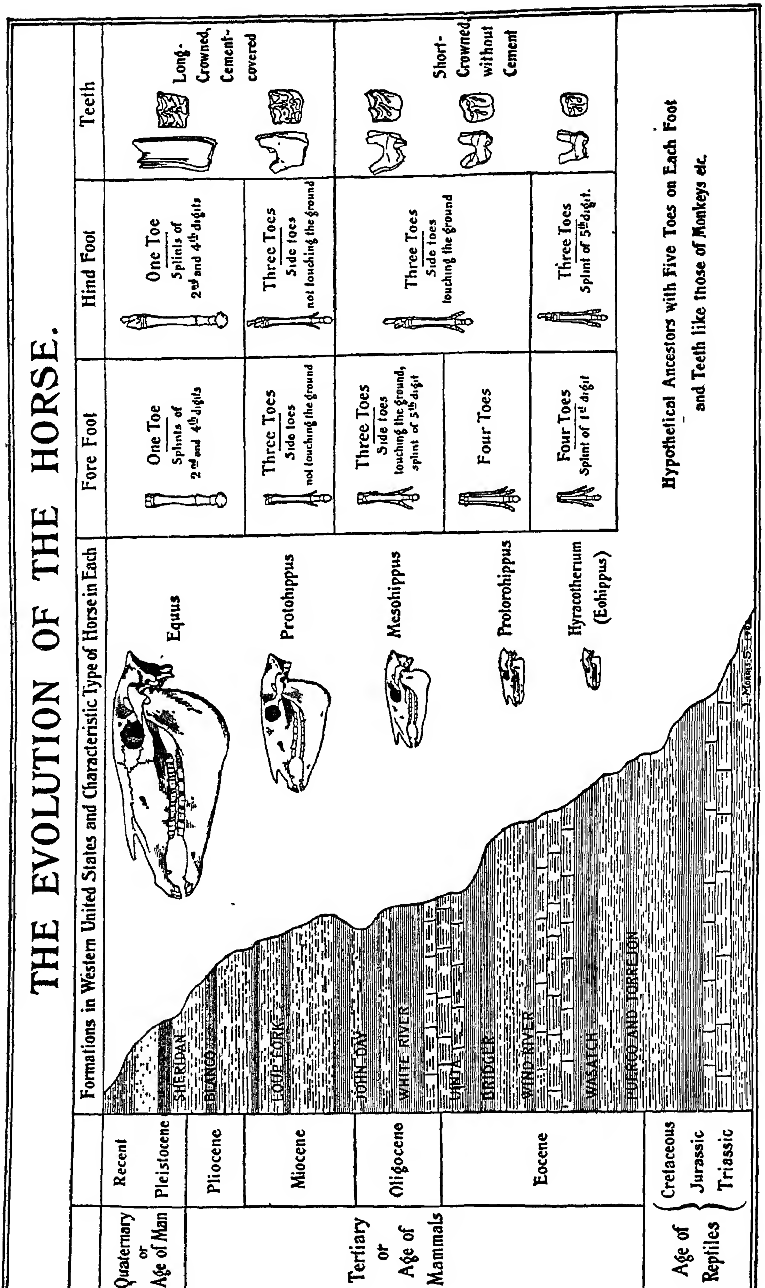


FIG. 456.—The evolution of the horse. (After William D. Matthew, Am. Museum Journal.)

for the great wear caused by the dry silicious grasses.[1] It is probably as safe to infer a development of dry grassy plains from this evolution of the horse, as to infer climatic and topographic conditions from plants and other organic adaptations, and hence it is probably safe to interpret the western "basins" as lodgment plains of the subaërial rather than of the strictly lacustrine type, so far as the nature of the deposits leaves the question open.

The tapirs and rhinoceroses.—The tapirs were but slightly represented, but the rhinoceroses, though the running and swimming branches had dropped away, were a prominent feature in the fauna. The American species were still mainly hornless (*Aceratherium*), slight indications of horns appearing in a single genus (*Diceratherium*). Two-horned species, however, appeared during the period in Europe.

The carnivores.—The carnivores were abundant, and had assumed forms referred with some doubt to the living genera *Canis*, *Felis*, *Mustela*, and *Putorius*. The *Canidæ* embraced numerous wolves and foxes, the *Felidæ*, panther-like animals and saber-toothed cats, the *Mustelidæ*, weasel-like and otter-like forms, and an ancestral coon is recorded. The genera of the Loup Fork horizon were nearly all different from those of the John Day horizon, which indicates rapid evolution. In Europe, in addition to these four families, the bear, civet, and hyena families were represented, thus including the seven existing families of carnivores.

The rodents were represented much as in the earlier epoch. Neither the insectivores nor the primates appear in the North American record. The development of the plains which favored the horses, deer, and cattle, was obviously unfavorable to the lemuroids.

The primates in the Old World.—In the Old World, the true apes, *Oreopithecus* and *Dryopithecus*, appeared. The former was a rather large annectant form uniting some of the characters of the apes and the monkeys; the latter was a generalized type related to the chimpanzee and gorilla, and about as large as the former. It is the view of some paleontologists that the ancestral branch of the *Hominidæ* must have diverged from its relatives at least as early as this, since, for anatomical reasons, it could not well have been derived from the *Simiidæ*,

[1] An excellent recent statement of the evolution of the horse, admirably illustrated, is given by Matthew. Sup. to Am. Mus. Jour., Vol. III, No. I, Jan , 1903, Guide Leaflet No. 9.

and this family had already become differentiated; but on the derivation of the *Hominidæ* the record throws no immediate light.

The marsupials.—The marsupials were but meagerly represented in America or Europe, and the period witnessed the last appearance of the opossum in Europe. The state of the marsupials and monotremes in Australia, where they came into dominant importance later, is undetermined.

The lower vertebrates.—Little of moment is recorded relative to the lower vertebrates. Not much is known of American Miocene birds, but their advancement in later stages implies that they continued their evolution with measurable rapidity, and this is supported by the European evidence. The reptiles had very generally assumed the modern forms, and were represented by turtles, snakes, and crocodiles. The amphibians came again to notice in the form of a large salamander, whose remains, found at Oeningen, Switzerland, formerly attained an unworthy celebrity from false identification as a human skeleton, and from the application of the pretentious designation, *Homo diluvii testis*.

Summary.—A general view of the American Miocene fauna shows that the great order of ungulates took precedence in evolution and that both the odd- and even-toed branches participated actively. Closely following these in importance, and dependent on them for the conditions of their evolution, came the carnivores, while the rodents occupied a median place, and the insectivores and lemuroids notably declined.

The European record bears a similar general interpretation, with the ungulates somewhat less pronouncedly in the lead, the carnivores somewhat better deployed, and the proboscidians a conspicuous factor, while the important evolution of the higher primates seems to have been wholly confined to the Old World.

The Marine Life.

Provincialism dominant.—The pronounced provincialism that had been inaugurated in the Oligocene epoch continued throughout the remainder of the Cenozoic era. There was some amelioration during the Miocene, but it was not marked. No essential relief was possible so long as the shallow seas remained mere bordering tracts, as in North America, or mere bays and straits, as in Europe. Even the border

tracts that were geographically continuous, though narrow, show signs of having been cut into biological sections by special interrupting agencies. Such barriers had perhaps been operative in certain provincial periods before, but they were not so well recorded as now. The land area being large, great rivers joined the coast here and there and poured volumes of fresh and muddy waters across the shore belt, doubtless forming barriers to some species, though probably not to others. The warpings of the crust probably projected peninsulas and submarine ridges out upon and perhaps across the continental shelf, and these were not only barriers in themselves, but supplemented their own influence by directing the courses of the coast currents. As differences of climate in different latitudes had apparently been developed, cold and warm currents were probably more active than in the previous times of more uniform climate, and their shiftings had still graver effects upon the faunas. So too, the lower temperatures in the northern shore tracts of the Atlantic and Pacific shut off these tracts from serving longer as migratory routes for the warm-water species, and this further tended to intensify the provincial nature of the shallow-water faunas.

According to Dall,[1] the Chesapeake Miocene was ushered in by a marked faunal change due to a cold northern current driving out or destroying the previous warm-water fauna of the region, and bringing with it a cold-water fauna. There was a complete change of species, and even some genera were displaced. The fauna retained, however, a general molluscan aspect. Both the bivalves and the univalves gave proof of better adaptability to the vicissitudes of the coastal tracts than most other forms, and whether warm or cold waters prevailed, held their dominance. Figs. 457 and 458 show a few of the characteristic types. Compared with the Eocene group, Fig. 434, the resemblances will be found, by the untechnical observer, more striking than the differences.

Notwithstanding the provincializing agencies, there were many close correspondences between the faunas of the western and the eastern sides of the Atlantic, probably due partly to intermigration and partly to parallel evolution. These correspondences have been set forth by Dall in the following quotation:[2]

"In a general comparison of the European and American Miocene we find, among other things which may be cited as parallelisms: in land vertebrates

[1] Papers previously cited. [2] Md. Geol. Surv., Miocene volume, 1904, pp. cli–cliii.

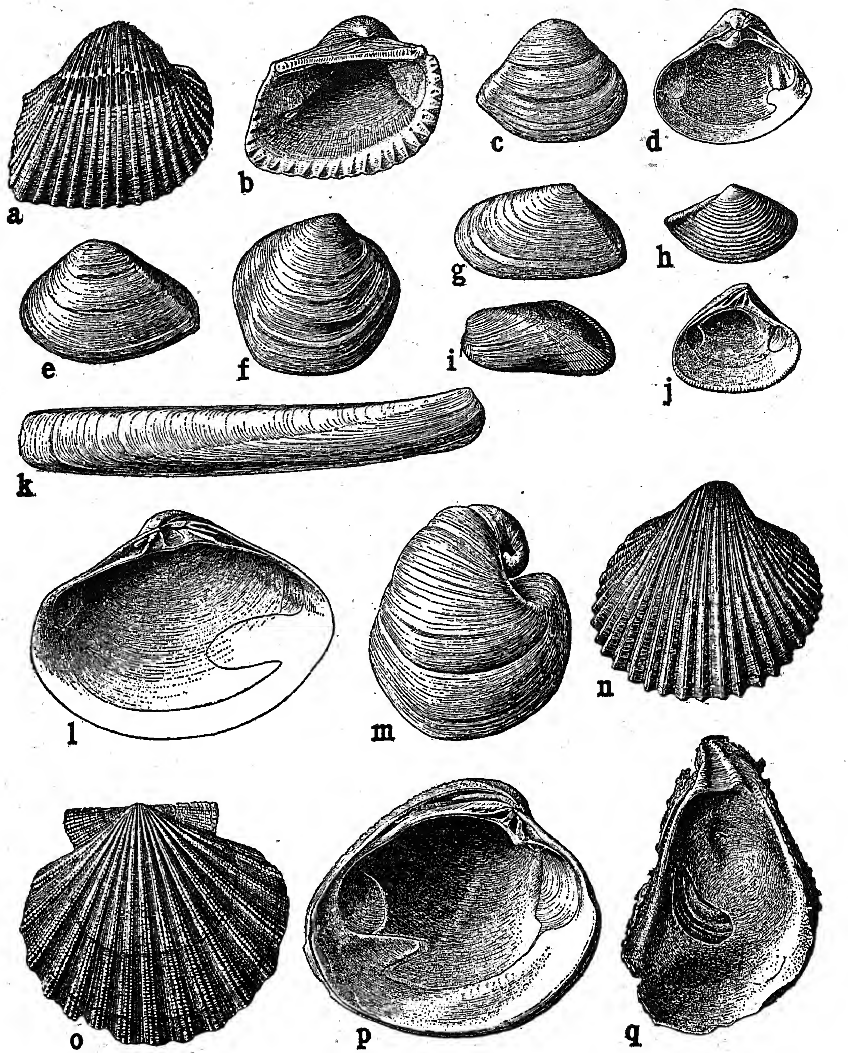


FIG. 457.—MIOCENE PELECYPODS: *a* and *b*, *Arca* (*Scapharca*) *staminea* Say; *c* and *d* *Corbula idonea* Conrad; *e*, *Crassatellites marylandicus* (Conrad); *f*, *Phacoides* (*Pseudomiltha*) *foremani* (Conrad); *g*, *Tellina* (*Angulus*) *producta* Conrad; *h*, *Leda concentrica* (Say); *i*, *Modiolus dalli* Glenn; *j*, *Astarte thomasii* Conrad; *k*, *Ensis directus* (Conrad); *l*, *Spisula* (*Hemimactra*) *marylandica* Dall; *m*, *Isocardia markoëi* Conrad; *n*, *Cardium* (*Cerastoderma*) *leptopleurum* Conrad; *o*, *Pecten* (*Chlamys*) *madisonius* Say; *p*, *Venus ducatelli* Conrad; *q*, *Ostrea carolinensis* Conrad. (After Maryland Geological Survey.)

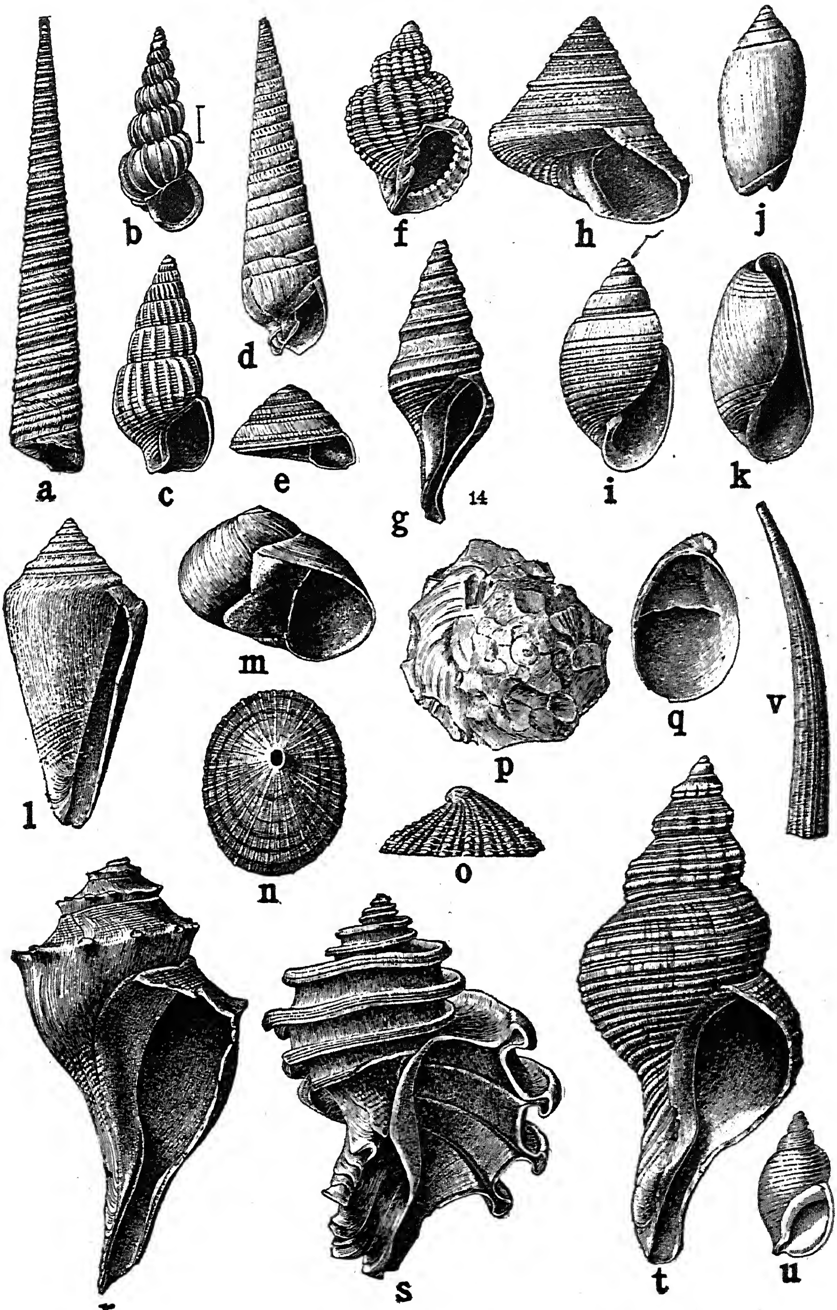


FIG. 458.—MIOCENE GASTROPODS (one Scaphopod).

the Sansans and Deep River mammals, and among cetaceans the presence of *Squalodon*, *Balæna*, *Priscodelphinus* and other dolphins. Among the sharks may be cited *Carcharodon megalodon*, *Hemipristis serra* and *Notidanus primigenius*. *Oxyrhina*, *Carcharias*, *Galeocerdo* and various rays were abundant in the sea bordering the western continent during this period.

"In Europe corals are rare except at the south; in Maryland *Astrohelia* and *Septastrea* represent the group, the waters of Chesapeake time in this region having been too cold for reef corals and too shallow for the deep-sea forms.

"The Echinoids of the Miocene are as a rule few in species and profuse in individuals; *Clypeaster*, *Scutella*, and *Spatangus* being the most prominent of European, *Amphidetus* and *Scutella* of American forms.

"Among the Vermes *Spirorbis* is conspicuous, and *Balanus* among the Crustaceans.

"Among the Foraminifera nummulites are absent, and, in America, *Orbitoides*. *Amphistegina*, *Ehrenbergia*, *Cassidulina*, and *Ellipsoidina* are prominent in Europe, *Polystomella*, *Planorbulina*, *Rotalia*, *Textularia*, *Polymorphina*, and *Uvigerina* in America. *Lithothamnion* is a common fossil in the marine Miocene of both continents.

"There are left the Mollusca, which we may examine a little more closely.

"Cephalopods are rare in the Miocene. The *Aturia*, which in America does not persist beyond the middle of the Oligocene, in Europe is said to linger a little longer. *Nautilus* is known from both the east and west coasts of America in the Miocene.

"In America, among the Toxoglossate gastropods, *Terebra* (represented by species of the subgenera *Hastula* and *Oxymeris*) is notable, there are many Pleurotomoids, the cones are few and coarse, *Cancellaria* is represented by a notable number of species. The same remarks apply almost equally to the North German Miocene.

"American Rhachiglossa are numerous. A species of *Oliva* and one of *Scaphella* at least appear in both America and North Germany. *Busycon* in the former region is represented by *Tuicla* in the latter. *Fusus* is more abundant in Europe than in America, but the peculiarly characteristic Miocene subgenus of *Chrysodomus*, *Ecphora*, is represented in North Germany by a form almost intermediate between the American *E. quadricostata* and *Chrysodomus decemcostatus*. *Ancilla*, *Murex*, *Purpura*, and *Tritia* are conspicuous in the Miocene faunas of

EXPLANATION OF FIG. 458.—*a*, *Turritella variabilis* Conrad; *b*, *Scala sayana* Dall; *c*, *Nassa marylandica* Martin; *d*, *Terebra unilineata* Conrad; *e*, *Solarium trilineatum* Conrad; *f*, *Cancellaria alternata* Conrad; *g*, *Surcula biscatenaria* Conrad; *h*, *Calliostoma philanthropus* (Conrad); *i*, *Actæon shilohensis* Whitfield; *j*, *Oliva litterata* Lamarck; *k*, *Retusa* (*Cylichnina*) *conulus* (Deshayes); *l*, *Conus diluvianus* Green; *m*, *Polynices* (*Neverita*) *duplicatus* (Say); *n*, *Fissuridea alticosta* (Conrad); *o*, *F. griscomi* (Conrad); *p*, *Xenophora conchyliophora* (Born): *q*, *Crepidula fornicata* (Linné); *r*, *Fulgar spiniger* (Conrad) var.; *s*, *Ecphora quadricostata* (Say); *t*, *Siphonalia marylandica*, Martin; *u*, *Ilyanassa* (?) (*Paranassa*) *porcina* (Say). SCAPHOPOD: *v*, *Dentalium attenuatum* Say. (After Maryland Geological Survey)

Europe, *Ptychosalpinx*, *Ilyanassa*, and *Tritia* in America. The *Melanopsis* of Europe is paralleled by the *Bulliopsis* of America.

"Among the Tænioglossa, *Turritella* is conspicuous in both continents; a form of *Cassis* (*Cassidaria* or *Sconsia*) is equally present. *Cypræa* is more numerous in Europe, but represented in both regions; *Pyrula* occurs in both, more abundantly in Europe; as do the various types of *Tritoniidæ*, such as *Septa*, *Lotorium*, and *Ranella*. *Pyrazus* is more abundant in Europe and the *Calyptræidæ* in America.

"Among the Rhipidoglossa, *Calliostoma* is more representative in America and *Gibbula* in Europe.

"Turning to the bivalves we find an equally noticeable parallelism. In Europe *Glycymeris*, *Barbatia*, and *Scapharca* are very characteristic, as they are in America. *Ostrea* is large and numerous, large *Pectens* occur, though the latter are perhaps less characteristic of the Miocene than in America.

"The conspicuous place of the *Cardiums* in our Miocene is hardly filled by the species in the European faunas, where also we find a notable number of *Isocardia*. *Mactra* in Europe is represented by *Spisula* in America. *Panopea* is about equally conspicuous in both, *Cardita* more so in Europe, *Astarte* in America. *Corbula* and *Saxicava* are equally common to both regions. The very characteristic *Mytiloconcha* occurs in both. A host of uncharacteristic forms, such as *Nuculidæ*, *Abra*, *Tellina*, *Ensis*, *Macrocallista*, *Timoclea*, *Lima*, *Phacoides*, etc., are common to both, but in Europe *Venerupis*, *Paphia*, *Eastonia*, *Lutraria*, *Cardilia*, *Pecchiolia*, *Congeria*, and *Adacna* are found with no American Miocene equivalents. *Crassatellites*, *Crassinella*, *Agriopoma*, *Rangia*, *Mulinia*, *Melina*, occupy the same, or nearly the same, position on the western continent, where the giant species of *Venus* make their first appearance.

"In a general way, allowing for local peculiarities, the Miocene fauna of North Germany compares well and agrees closely with that of Maryland, while the Mediterranean Miocene finds a closer analogue in the more tropical fauna of the Duplin beds of the Carolinas. We have not in America any equivalent, faunally, of the *Congeria* beds of the Upper Miocene of eastern Europe."

CHAPTER XVIII.

THE PLIOCENE PERIOD.

The most distinguishing formational feature of the Pliocene is its aggradation deposits.[1] This is a consequence (1) of the exceptional deformations which took place during the period, and just before its beginning, and (2) of the recency of the deposition which has saved the formations, to a large extent, from removal. There is little doubt that similar deposits were made in similar amounts during and after other periods of comparable deformation, but they have been largely swept away by subsequent erosion. The Pliocene deposits will suffer the same fate if the continent remains quiescent until another base-leveling, like that of the Cretaceous, is accomplished.

Simple and obvious as the method of terrestrial aggradation is, and illustrated in a small way in almost every tract of diversified topography, its results are less clearly recognized than those of most other phases of sedimentation, and their identification, correlation, and precise interpretation are attended with difficulties much beyond those which attend typical marine, lacustrine, and fluviatile deposits. Of the major examples of Pliocene deposits of this class, those formed in the intermontane basins, abundantly exemplified in the Great basin, are the most obvious and unquestioned, though largely misinterpreted as lacustrine deposits. Lacustrine deposits are, however, present and extensive in this region.

[1] In its broadest sense, all sedimentary formations on land or under water are aggradational, but deposits under seas and lakes have their own distinctive terms, marine and lacustrine, and deposits made in the channels or on the flood plains of rivers have their designations, fluvial or fluviatile, and alluvial. The term aggradation is coming into use to designate a group of complex deposits that take place on land partly by overburdened rivers, but quite largely by temporary streamlets, slope-wash, "sheet-wash," and miscellaneous agencies that remove material from uplands and deposit it on flat lands, and it is in this sense that it is employed here.

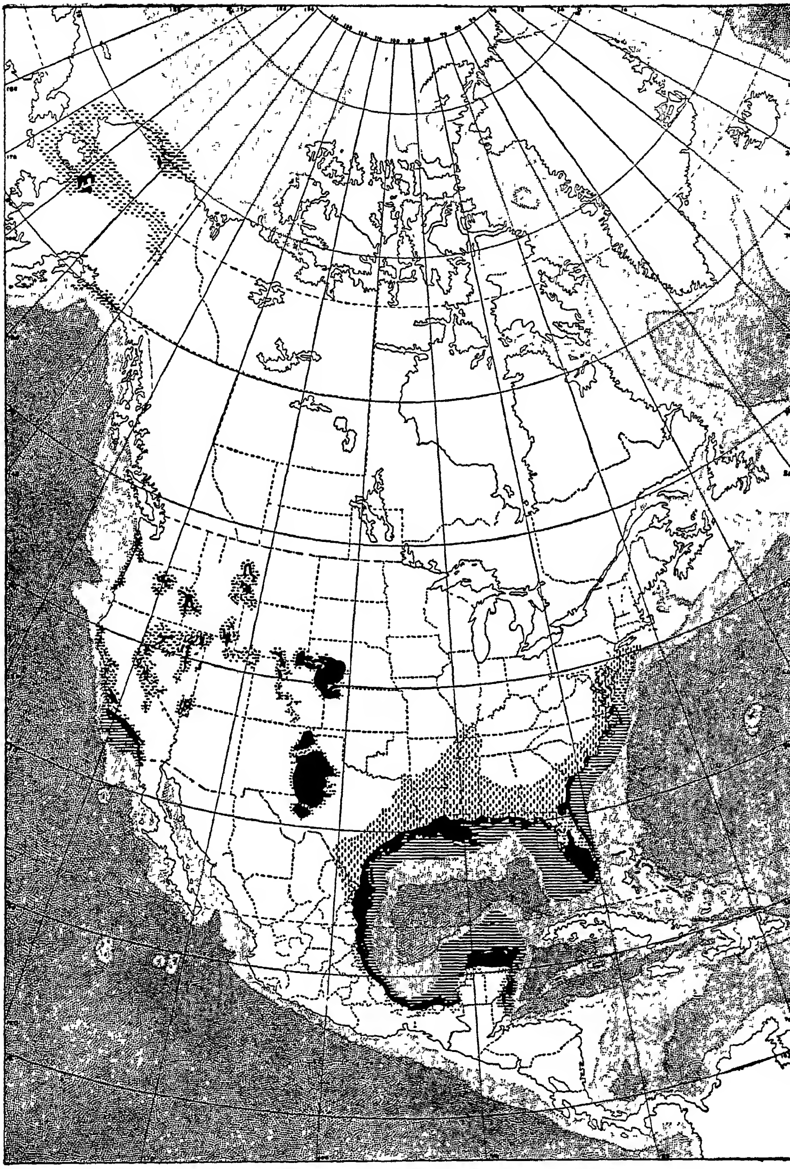


FIG. 459.—Map showing the distribution of the better known parts of the Pliocene system. The conventions are as in other maps, except that the area of the Lafayette, along the Atlantic and Gulf coasts, is marked by vertical dashes. This formation is doubtless more wide-spread than the map shows, as indicated in the text. Relatively little of the exposed Pliocene is marine.

Over areas much greater than those occupied by lakes in Pliocene times, and over tracts which never formed parts of definite flood plains, broad aprons of detritus brought from the higher slopes are accumulating now, and similar accumulations were quite surely making in Pliocene times. Such accumulations are most considerable on the flanks of mountain ranges where precipitous slopes join plains of low gradient. Particularly is this the case where the climate is sub-arid, and the rain falls in sudden and copious showers, largely concentrated on the mountain heights, while the thirsty plains below, covered with porous wash, quickly drink up the sudden mountain floods and strand the detritus which they brought down in their swift descent. Most of the western mountains of America are flanked by such deposits, which sometimes spread far out upon the adjacent plains. A portion of these deposits are of Pliocene age, and a portion are still younger. In basins occupied by lakes, these subaërial sediments merge into lacustrine deposits, and, as a consequence of the fluctuations of the lakes, are more or less interstratified with them. They also merge so insensibly into true flood-plain deposits that they cannot be systematically separated from them; nor should they be, since they are of the same essential nature. If slopes are suitable, deposits on plains free from standing water are likely to be more extensive than lacustrine deposits, for the whole plain is then open to subaërial aggradation free from competitive lacustrine catchment. It is probably safe to affirm that Pliocene deposits of this type lie concealed beneath later accumulations of a similar sort in nearly all the large basins, and at the bases of nearly all the steep slopes in the western mountain region. Positive proof of their presence is difficult, both because of the difficulty of distinguishing them from later deposits physically, and because of the paucity of fossils. The Pliocene deposits of this sort which have been identified are probably but a small fraction of all that exist.

On the whole it would appear that erosion was the dominant process in the Cordilleran region during this period, but that a not inconsiderable part of the eroded material was left in basins and valleys and on plains, not far from its source.

Among the formations which have been described, usually as lacustrine, from the area west of the Rocky mountains, are those of the Great basin[1] and

[1] King, Geol. Expl. of the 40th Parallel, Vol. I, pp. 525–543.

certain parts of Colorado (North Park, North Platte, etc.). In some cases their areas are large, though their boundaries are undetermined. They have been assigned thicknesses ranging up to 1400 feet, and they contain much volcanic débris. They are said to be unconformable on the Miocene, which they overlap in all directions. The later auriferous gravels [1] of California (Fig. 460) already referred to under the Miocene, belong to this class. Their deposition, begun in the Miocene, was continued into the Pliocene, and probably even into the succeeding period. Deposits of similar origin probably abound throughout the western mountains, but, except where the latter are of glacial

FIG. 460.—Section showing auriferous gravels, *Ng*, overlain by rhyolite tuff, *Nr*, and andesite, *Na*. Length of section 1¼ miles. (Lindgren, Nevada City, Cal. Special folio, U. S. Geol. Surv.)

or fluvio-glacial origin, they have few characteristics which distinguish them from later deposits.

Sedimentation (Rattlesnake beds) appears to have continued during the Pliocene in the John Day basin,[2] where the aggregate thickness of the Tertiary beds is said to exceed 10,000 feet.[3] Pliocene beds are also reported from Idaho (Idaho formation), where they overlie the Payette (Eocene) formation unconformably,[4] from New Mexico,[5] Arizona,[6] and Mexico [7] (Sonora). Non-marine sedimentary beds are also said to be of common occurrence in the southern Coast ranges of California,[8] and are reported from the coastal plain of northern Alaska, where the sequoia grew [9] in latitude 70°, or thereabout.

East of the Rocky mountains, on the border of the Great plains, deposits of this class have been noted at many points, but a demonstrative interpretation is as yet generally lacking. Some of them have been referred to the Pleistocene, but many so referred are probably older. In many places these formations show by their constitution that the source of their material was in the western mountains. In

[1] See references to Auriferous Gravels under the Miocene, p. 274.

[2] Merriam, Bull. Dept. of Geol., Univ. of Cal., Vol. II, p. 312.

[3] Merriam, Bull. Geol. Soc. of Am., Vol. XII, p. 496.

[4] Lindgren and Drake, Nampa and Silver City folios, U. S. Geol. Surv.

[5] Reagan, Am. Geol., Vol. XXXI, p. 84.

[6] Blake, Sci., Vol. XV, N. S., p. 413, and Dumble, Am. Inst. Min. Eng., Vol. XXXI, p. 696.

[7] Dumble, Trans. Am. Inst. Min. Eng., Vol. XXXI, p. 696, XXIX, p. 691, 125.

[8] Fairbanks, Jour. of Geol., Vol. VI, p. 565.

[9] Schrader, Bull. Geol. Soc. of Am., Vol. XIII, p. 249.

some situations the gravels have been shifted repeatedly, always farther from the mountains and to lower levels, with the result that they now constitute a series of deposits, of somewhat different ages, rather than a single formation which can be assigned to a definite epoch.

Here are to be classed, probably, the Nussbaum formation of Colorado,[1] and equivalent but unnamed bodies of gravel in Wyoming, Montana, and New Mexico, and, farther from the mountains, the Goodnight beds of Texas, unconformable on the Loup Fork, the Uvalde [2] and Blanco formations of the same state, the latter consisting of sands, clays, diatomaceous earths and some limestone [3] (Reynosa, non-marine), as well as gravel. Gravels of similar age occur in Kansas [4] (often cemented into "mortar beds") and western Nebraska [5] (Ogalalla formation).

Formations of this class have been even less well recognized in the Old World, but from the descriptions of the Indian geologists, it seems probable that the great Siwalik formation, a derivative from the Himalayas in their rising stage, belongs to this class. The enormous and abrupt elevation of the Himalayas, in close juxtaposition to the great Indo-Ganges plain, presented extraordinarily favorable conditions for such a foot-plain deposit, and the Siwalik formation may come to be the classic example of aggradational deposition.

The juxtaposition of precipitous heights and flat plains is not the sole condition for aggradational formations. A less sharp differentiation between feeding and lodgment grounds will suffice, when adjustments are favorable.

In the Mississippi basin, far from the Rocky mountains on the west and the Appalachians on the east, there are patches of gravel on various hills and ridges, which are interpreted as the dissevered remnants of a once more or less continuous mantle of gravel and other river detritus. Data are not at hand for the definite correlation of these gravels, and they may not all be of the same age. They are not older than late Cretaceous, and are older than the glacial drift. The source of this material, which is almost wholly quartz, quartzite, and chert, is partly local, but apparently more largely from the north.

[1] Walsenburg, Spanish Peaks and Pueblo folios, U. S. Geol. Surv.

[2] Vaughan, Uvalde folio, U. S. Geol. Surv.

[3] Penrose, 1st Ann. Rept. Geol. Surv. of Tex., 1890, p. 63, and Dumble, Jour. of Geol., Vol. II, p. 562.

[4] Haworth, Geol. Surv. of the Univ. of Kans., Vol. II.

[5] Darton, 19th Ann. Rept. U. S. Geol. Surv., Pt. IV.

The similarity of these gravels to the Lafayette farther south suggests their correlation with that formation. Perhaps a better view is that they are the older part of the complex series of river deposits, shifted repeatedly to lower levels, and nearer the sea, until the main part of the series is now near the coast, while only meager remnants remain in the sites of original deposition. The farther these remnants are from the low coast-plain the smaller they are and the greater their altitude, and if the above interpretation be correct, the greater their age. In other words, the remnants become larger, lie at lower levels, and are presumably younger, to the southward, where they seem to grade down to the more continuous Lafayette formation soon to be described.

The patches of gravel here referred to are found in Minnesota,[1] Wisconsin,[2] Iowa, Illinois,[3] Arkansas,[4] Indiana,[3] Kentucky, and Tennessee. The leading topographic features of the Mississippi basin have been developed since the deposition of these gravels, for their northern remnants are on the crests of the highest lands within the areas where they occur.

Reference was made to the phase of deposition here set forth in connection with the Potomac series (p. 112), and the phenomena seem to have been repeated in the same region, in much the same way, in the Pliocene, giving rise to the Lafayette formation, known earlier in the Mississippi basin as the Orange sands. This formation has been, and still is, the occasion of so much difference of opinion that it merits special consideration. It should be said, in prudence and fairness, that the interpretation here given it is not unchallenged, and the alternative views will be indicated later.

The Lafayette Formation.[5]

The Lafayette formation has an extensive distribution between the Appalachians and the Atlantic, and in the Mississippi basin, and is repre-

[1] 24th Ann. Rept. Minn. Geol. Surv., p. xxv.

[2] Jour. of Geol., Vol. III, p. 655.

[3] Bull. Geol. Soc. of Am., Vol III, p. 183; see also references given in this paper.

[4] Geol. Surv. of Arkansas, Report on Crowley's Ridge, and also Am. Jour. Sci., Vol. XLI, 1891, pp. 359–377, and Vol. XLII, p. 252.

[5] The fullest account of this formation as a whole is that of McGee in the Twelfth Annual Report of the U. S Geological Survey. References to other accounts of the formation in special localities, often under other names, are as follows: Safford,

sented, if our interpretation be correct, in the valleys west of the Appalachians. An analogous formation is found on the Coastal plain of Texas, and, by inference at least, this is associated with analogous deposits on the Great plains, and through them with the intermontane deposits of the west, already mentioned. The term Lafayette has been usually applied only to the formation on the slope between the Appalachians and the Atlantic, to that in the Mississippi basin below the junction of the Ohio, and to the Texan tract. The formation thus limited has been estimated to have an area of from 200,000 to 250,000 square miles. It lies like a blanket over the eroded edges of all the older formations of the region, from the pre-Cambrian to the Miocene. It extends inland from the coast up to varying altitudes. In Mississippi, its landward edge is said to reach an elevation of 500 or 600 feet; in Tennessee, 800 feet; at Austin, Texas, 500 feet, and near the Rio Grande, 1000 feet[1]; but on the Atlantic slope, the elevation is generally less.

At its mountainward edge, ragged belts of the Lafayette formation follow the valleys up into the mountains, and unless our identifications be in error, they reach back through the gaps, where they are locally interrupted, into the intermontane valleys. Between the valley phases, its mountainward edge recedes and is ragged, and has not yet been carefully mapped. At its seaward margin, the formation is more or less completely concealed by younger beds. It is not to be doubted that the Lafayette formation or its equivalent passes out to sea beneath these younger beds. Indeed, there is some reason to believe that at some points it is replaced within the present land-area, by marine beds, as such a formation is very liable to be where the plain on which it was deposited slopes gently to the sea. But such marine deposits as can be correlated, even hypothetically, with the

Geology of Tenn. (Bluff Gravels), and Am. Jour. Sci., Vol. XXXVII, 1864; Hilgard, Agriculture and Geology of Mississippi, 1860, and Am. Jour. Sci., Vol. XLI, 1866, and Vol. IV, 1872; Loughridge, Kentucky Geological Survey; Jackson Purchase Region, 1888; Geology of Illinois, Vol. I, pp. 417 and 447; Salisbury and Call, Geol. Surv. of Ark., Report on Crowley's Ridge, 1889; Hill, Am. Geol., Vol VII, 1891, p. 368, and (with Vaughan) Uvalde formation of Texas, 18th Ann. Rept. U. S. Geol. Surv., Pt. II, p. 560; Dumble (Blanco Formation of Texas), Jour. Geol., Vol. II, 1894, p. 560; Smith, E. A., and Johnson, L. C., Geol. Surv. of Ala., 1894. For synonyms of the formation, see Am. Geol., Vol. VIII, 1891, pp 129–131, and Bull. 84, U. S. Geol. Surv., p. 328.

[1] McGee, loc. cit.

Lafayette, probably correspond to but a limited part of the complex formation whose elements are many and intricate. On the west side of the Appalachians, the formation seems to be essentially continuous in the Tennessee valley as far north as Knoxville at least.

The base on which the Lafayette formation rests is of slight relief, and appears to have been either in an advanced stage of erosion when the Lafayette formation was deposited, or too low to have become notably rough as a result of erosion. In addition to the relief determined by erosion, the surface had a gentle slope to seaward.

Thickness.—Like most sedimentary formations, the Lafayette is variable in thickness. In general, it thickens seaward, and thins in the opposite direction; but at any given distance from the sea, it is thicker in the valleys which affected the surface on which it was deposited, and thinner on the divides between them. The thickness ranges from nothing to 200 feet or more. Sections of 20 or 30 feet are common, and thicknesses greater than 50 feet are rare.

Constitution.—The Lafayette is a very heterogeneous formation, composed of gravel (and occasionally bowlders two or three feet in diameter), sand, silt, and clay, variously related to one another. It may be said to be both heterogeneous and homogeneous; that is, there is considerable variation in its material within short distances, and but little more in great ones. In the lower Mississippi valley, where the formation first attracted serious attention, and whence the name is derived (Lafayette County, Miss.), it is predominantly of sand and gravel, the coarser phases along drainage lines. In these tracts it has usually the distinctive characteristics of fluvial sands and gravels. The formation assumes a different phase over a broad tract of the uplands east of the Mississippi and away from valleys generally. In such situations it is composed largely of silt and clay. Some of the clay is of exceedingly fine texture, and from such clay there are various gradations into silt and sand. The formation is largely composed of the insoluble residue of the older formations farther up the slope on which the mantle lies, chert and quartz pebbles making up the gravels, and other insoluble matter the fine constituents.[1] These constituents replace one another at short intervals and in various ways, and no systematic succession is observable. Lens-like masses

[1] Hilgard long ago pointed out (Am. Jour. Sci., Vol. IV, p. 266, 1872) that the formation contains almost nothing which can be oxidized or readily dissolved.

are not uncommon. Irregular stratification is the rule, but some portions are not bedded or laminated. Among such parts are singular lenses of sand which suggest an eolian origin. While assortment generally prevails, it is very often irregular and imperfect. A singular pebble-earth that finds its analogue in subaërial and flood-plain deposits is common, but, so far as we know, has no representative in marine and lacustrine deposits.

Color.—The coloration of the formation is significant, ranging from brick-red through various pinks, purples, oranges, and yellows to white. The color is more irregular than the composition, bands, blotches, and mottlings diversifying the structural units. Where an ancient, if not the original, surface of the Lafayette is preserved by an overlying deposit, such as the loess, there is often a highly colored, sub-surface zone, analogous to the sub-surface coloration of the later deposits which cover it. This coloration is partly inherent in the material, but more largely the result of a thin coating of red ferric oxide enveloping the grains. Its significance is thought to lie in its suggestion of the climatic conditions which accompanied or followed the deposition of the formation, conditions under which the depositional action of sub-surface waters was greater than their leaching effects. Such conditions are assignable to effective dry seasons.

Partial removal of the formation.—Something has already been said with reference to the general distribution of the Lafayette formation, but it is not to be understood that it occurs everywhere within the area specified. As a result of stream erosion the formation is discontinuous. Over considerable areas, it caps divides, but is absent from the valleys between them. In many places its remnants are best preserved where the substratum is resistant rock, and less prevalent where the substratum is rock which is easily eroded.[1]

In Mississippi[2] and Alabama[3] a considerable belt underlain by the Selma (Rotten) limestone is essentially free from the formation; so also is the belt underlain by the Jackson or White limestone, and the belt underlain by parts of the Lower Eocene[4] (Black Bluff, or

[1] Smith, Geology of Alabama, 1894.

[2] Hilgard, Agr. and Geol. of Miss., 1860, p. 5.

[3] Smith, Geol. Surv of Ala., 1894, p. 68.

[4] McGee also points out the absence or meagerness of the formation over calcareous sub-terranes,12th Ann. Rept. U. S. Geol. Surv..

Sucarnoche of Alabama, Flatwoods of Mississippi). These belts are now rather lower than their surroundings, and the absence of the Lafayette from them has usually been assigned to subsequent erosion. An alternative interpretation, however, seems possible, in the light of present knowledge. The areas from which the Lafayette is absent are mainly underlain by calcareous formations. If they were divides when the Lafayette was deposited, and if in later time they have suffered more by solution than adjacent formations have by erosion, the present relations might have been brought about.

Fossils.—Fossils are rare in the known parts of the formation. In the unquestioned and representative portions of the Lafayette, all are of land plants and animals (except, of course, the fossils derived from earlier formations). The formation is much dissected and unusually open to observation, so that the observed rarity of fossils must be taken as really representative. As already remarked, it is probable that seaward equivalents of the Lafayette contain marine fossils.

Genesis.—As here interpreted, the Lafayette formation belongs to an important class, long neglected, but now coming into recognition, whose distinctive features are less critically familiar than those of marine, lacustrine, and typical fluviatile formations. The preferred interpretation is as follows: After the Cretaceous base-leveling of the region, brought out by Davis,[1] Hayes,[2] Campbell, and others, the Appalachian tract was bowed up and a new stage of degradation inaugurated. During the long Eocene period, a partial peneplaning of the less resistant tracts was accomplished. This was slightly interrupted by the Oligocence deformation, and the streams mildly rejuvenated in the more responsive tracts. During the Miocene period, base-leveling was resumed, abetted by relative subsidence along shore, as indicated by the landward spread of the Miocene sea, and the open low-grade valleys and abundant low cols of the region west of the Appalachians, if the interpretation here given be correct. At the opening of the Pliocene, therefore, the Appalachian tract is supposed to have been affected by broad, flat, intermontane valleys, mantled by a deep layer of residual decomposition products. The Piedmont

[1] Rivers of Pennsylvania and Geographic Development of Northern New Jersey, Nat. Geog. Mag., Vol. I and Vol. II, respectively.

[2] Hayes, chapter on south Appalachians, in Physiography of the U. S. and 19th Ann. Rept. U. S. Geol. Surv., Pt. II; Hayes and Campbell, Nat. Geog. Mag , Vol VI.

tract skirting the Appalachians is supposed to have been flanked on the seaward side by a peneplain near sea-level, and on the other side by broad, open valleys of low gradient. It is assumed that the upward bowing was felt first in a relatively narrow belt along the predetermined axis, that the rise was gradual, and that the rising arch increased its breadth as it rose. The first bowing along the axis rejuvenated the head waters of the streams which reached it, and the surface, deeply mantled with residuum accumulated during the peneplaining stage, readily furnished load to the streams in flood stages. When the streams reached that portion of the peneplain not yet affected by the bowing, they found themselves loaded beyond their competency, and gave up part of their load. Thus arose a zone of deposition along the bowed tract, as illustrated in Fig. 461. With continued rise, the

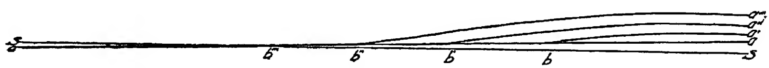


FIG. 461.—Illustrating the progressive stages of arching described in the text, and the attendant shifting zones of deposition; *s–s*, sea-level; *a*, original peneplaned surface with graded slope to sea-coast; a', a'', a''', successive stages of arching; b, b', b'', b''', successive zones of deposition corresponding to stages of arching a', a'', a'''. In the stage of arching represented by a'', the right hand portion of the previous zone of deposition is lifted and becomes a part of the area of erosion. The same process is carried farther in the next stage represented by a'''.

mountainward border of the depositional zone is supposed to have been shifted seaward, and the previous border elevated and subjected to erosion, while the material removed was re-deposited in a new zone farther from the axis of rise.

Thus the process is presumed to have continued till the border of the lifted tract passed beyond the present sea-coast, after which the whole mantle was subject to erosion, which had reached a notable degree of advancement before the first known glacio-fluvial deposits were laid down.

The hypothesis requires that the aggradation in each depositional zone, when at its maximum, should develop a plexus of streams competent to fill the shallow valleys and spread rather generally over the low divides of the coastal peneplain, where relief was slight. In the region of more pronounced valleys, such as the Tennessee, the valleys were only partially filled. It has generally been assumed that the formation was once continuous in the areas where patches only now remain; but it may be that the higher divides, especially

toward the source of sediment supply, were never mantled by the formation.

As set forth in Volume I, the overloading of streams is greatly affected by the mode of precipitation and the vegetal covering of the region. Diversifying agencies, particularly when attended by subaridity, tend toward concentrated precipitation, which greatly accelerates erosion. A change of vegetal covering, generally involving a decrease in the amount of protection, usually accompanies a climatic movement toward diversity and aridity, particularly if a reduction of temperature attends the change. All these abetting agencies are assignable with good reason to the Pliocene movement, not only on general grounds, but on the specific implications of this formation, as already indicated.

The erosion and re-deposition of material once deposited in the manner sketched above, is regarded as an important feature, and the source of grave difficulty in the correlation of the formation and its derivatives. The erosion and re-deposition of the material during the deposition of the main formation did not cease there, but has been in progress to recent times, and the series of derivatives so closely resemble the parent formation in structure and material that their reference to their proper stages is exceptionally difficult. The close resemblance of the derivative deposits to the parent formation in structural features throws light on the mode of original deposition, for in some cases the later method is certainly known.

If it shall ultimately be shown that the seaward portions of the Lafayette, now concealed or unstudied, are marine, the preceding hypothesis would need to be modified only by supposing that as the feeding ground of the streams was bowed up, the coastal border of the plain was submerged. In this case, there should have been estuarine formations in the seaward valleys.

The chief alternative view relative to the origin of this strongly characterized formation assigns it to marine deposition[1] during a stage of submergence essentially co-extensive with the area of the formation. This hypothesis has been faithfully applied by geologists of wide familiarity with the phenomena and abandoned as untenable even where the conditions seem most to favor it. It is, however, still

[1] McGee, 12th Ann. Rept. U. S. Geol. Surv.

entertained by others. The difficulties felt by those who have abandoned it are (1) the absence of marine fossils even where conditions favor their preservation; (2) the presence of structural features not identical with those of typical marine deposits; (3) the chemical condition, particularly the high and very varying oxidation, and the meager hydration, with a general absence of the reduction phenomena connected with organic action beneath the sea; (4) the topographic relations of the formation, which are with difficulty reducible to the requisite horizontality; and (5) the absence of characteristic shore phenomena. Terraces have indeed been appealed to, but they are local and doubtfully consistent with one another, and seem better assignable to low gradient stream erosion through which this formation, under any interpretation, must have passed, in rising from its primitive low slope to its present higher one.

The Mississippi portion of this formation was formerly assigned to glacio-fluvial action connected with the Pleistocene ice invasions,[1] but this was due to its erroneous correlation with the Natchez formation, which is essentially a derivative from the Lafayette, with a glacio-fluvial contingent. It rests unconformably on the Lafayette, with notable erosion between the two.

Marine Pliocene Beds.

The Atlantic coast.—If fossils be the test, Pliocene beds of marine origin have but little development on the eastern side of the continent. In Florida only (Caloosahatchie beds)[2] have beds containing marine fossils any considerable extent at the surface, though small patches are known in Georgia, the Carolinas,[3] Virginia, and perhaps Massachusetts. The isolated outcrops in Virginia and farther south may be parts of a continuous formation, chiefly concealed by younger deposits. The beds in Massachusetts which have been regarded as Pliocene occur at Gay Head,[4] where they are unconformable on the Miocene. Farther south also, the relations of the Pliocene beds to their substratum is locally at least one of unconformity. The time

[1] Hilgard, Agr. and Geol. of Mississippi, 1860.

[2] Dall, Am. Jour. Sci., Vol. 34, 1887, p. 161, Wagner Free Inst. of Science, Vol. 14, Pt. VI, p. 1604, Bull. 74, U. S. Geol. Surv.

[3] Dall, Croatan beds of N. Carolina and Wassemer beds of South Carolina. Trans. Wagner Free Inst. of Sci, Vol. III, Pt. II, pp. 201-17, 1892.

[4] Dall, Am. Jour. Sci., Vol. 48, 1894, p 299.

relations of these marine Pliocene beds to the Lafayette are undetermined.

The marine fossiliferous Pliocene beds of the Atlantic coast consist of shell marls, sand, and thin beds of limestone. In Florida, the marine beds have a thickness of but a few feet. The gradual changes in the character of the marine fossils from below upwards in the beds show that a gradual shoaling of the water took place, until the species proper to a moderate depth were replaced by those characteristic of muddy shallows and tidal flats, and finally by an exclusively fresh-water fauna.[1]

In addition to the marine Pliocene of Florida, there seem to have been coastal lagoons and ponds in which fresh-water mollusks abounded. Occasionally, however, the sea had access to the lagoons, either as a result of slight changes of level of land or sea, or of severe storms, so that marine fossils are sometimes associated with those of fresh-water species. In addition to the coastal lakes and lagoons, there were lakes in the low interior syncline of the peninsula.[2]

The Gulf coast.—Pliocene beds of marine origin have not been certainly identified on the Gulf coast of the United States,[3] west of Florida, but they cover considerable areas farther south. Yucatan is generally covered with marine Pliocene, and corresponding deposits are known both to the north and south of that peninsula.[4] In general, the Pliocene beds of the tropical portion of the continent have not been clearly separated from the younger Pleistocene beds, with which their relations are said to be close. According to Hill, the great interruption in the Tertiary history of this region was in the later part of the Miocene, or at its close.[5] In the Antilles also, Pliocene beds are known on the borders of some of the islands.[6]

The Pacific coast.—On the Pacific coast, the post-Miocene emergence left little of the present land-area submerged; but a little later, coastal depression allowed the sea to encroach upon the land to a slight extent, and Pliocene beds were deposited unconformably on

[1] W. H. Dall and G. D. Harris, Bull. U. S. Geol. Surv., No. 84, p. 191.

[2] Ibid., De Soto beds, pp. 133, 324.

[3] The upper part of the Grand Gulf series is referred to the Pliocene by Smith and Aldrich, Science, New Series, Vol. XVI, p. 836.

[4] Gabb, Lumon clays. Jour. Acad. Nat. Sci. Phil., Vol. VIII, 1881, p. 349.

[5] The Geol. History of the Isthmus of Panama and Portions of Costa Rica.

[6] Hill, Geology and Physical Geography of Jamaica, 1889.

the Miocene, and on the older formations as well, at various points along the western borders of the Pacific states. In no case do the marine Pliocene beds extend far inland, though Pliocene beds containing marine diatoms are said to have been indentified in southern Arizona up to elevations of nearly 4000 feet.[1] During the Pliocene submergence, it has been thought that the islands of southern California stood some 1500 feet lower than now.[2] The thickest Pliocene beds of the continent, so far as known, are in the peninsula of San Francisco, where the Merced series (perhaps partly Quaternary,[3] and not all marine, as lignite shows) attains a thickness of more than 5800 feet,[4] and in the Santa Clara valley where the thickness of Upper Pliocene (partly fluviatile) is said to be 8000 feet.[5] Recently, a series of beds below the Merced series, aggregating more than 7000 feet in thickness and composed largely of volcanic debris, has been assigned to the Pliocene.[6] If this be correct, it gives the Pliocene of the Coast range near San Francisco bay a thickness of some 13,000 feet. In the San Luis Obispo region there are late Miocene or Pliocene formations (Santa Margarita and Pisma, shale, sandstone, conglomerate, etc.), of 4500 feet (maximum) thickness, overlain unconformably by Pliocene beds (Paso Robles) of non-marine origin, 1000 feet in thickness[7] (Fig. 444). Other names (San Diego[8] and Wildcat,[9] Cal., and Mytilus,[10] Ore.) have been applied to the marine Pliocene beds of various localities on the Pacific coast.[11] To some of these, as the

[1] Blake, Sci., Vol. 15, p. 413, and Dumble, Jour. Inst. Min. Engineers, Vol. 31, p. 696.

[2] Smith, Bull. Department Geol. Univ. of Cal., Vol. II. Reviewed in Jour. Geol., Vol. VIII, p. 780.

[3] The Messrs. Arnold, Jour. of Geol., Vol. X, pp. 117–138.

[4] Lawson, Bull Dept. Geol. Univ. of Cal., Vol. I, No. IV, p. 115 et seq. The upper parts of the Merced of Lawson is put in the Pleistocene by Ashley, Proc. Cal. Acad. Sci., 2d Ser., Vol. V, pp. 312–37, and the Messrs. Arnold, Jour. of Geol , Vol. X, p. 135.

[5] Hershey, Am. Geol., Vol. 29, pp 359–70.

[6] Lawson, Science, Vol. XV, p. 410, 1902. The correlation of the beds between the Monterey below and the Merced above, is not given in the publication. The opinion that they are Pliocene is expressed by the author in a letter.

[7] Fairbanks, San Luis, folio, U. S. Geol. Surv.

[8] The Messrs. Arnold, Jour. of Geol., Vol. X, p. 129, and Dall, Proc. Cal. Acad. Nat. Sci., Vol. VI, 1874.

[9] Lawson, Bull. Dept. of Geol. Univ. of Cal., Vol. I, p. 255 and Ashley, Proc. Cal. Acad. Nat. Sci., 2d series, Vol. V, 1895, pp. 312–331.

[10] Condon, Am. Nat , Vol. XIV, 1880, p. 457, and Dall, Bull. U. S. Geol. Surv.

[11] A good review of the Pliocene and Pleistocene of southern California is given by the Messrs. Arnold, Jour. Geol., Vol. X, pp. 117–38.

Wildcat, great thicknesses (4600 feet) have been assigned. Marine Pliocene beds are not known to have great development farther north, but beds tentatively referred to this period occur up to elevations of 5000 feet in the St. Elias Alps.[1] It has been thought that Vancouver and Queen Charlotte Islands were at this time connected with the mainland.

The fossils of the Pliocene beds of the Pacific Coast are said to indicate a climate cooler than the present.[2] This may have been the result of a broader connection than now between the Arctic and the Pacific.

Crustal Movements of the Pliocene.[3]

The tendency to crustal movement both by warping and by faulting, which characterized the western part of the continent during the earlier part of the Tertiary, seems to have continued at least intermittently through the Pliocene, though the movements which took place during the period are not always distinguishable from those of earlier times, or from those which took place at its close. Deforming movements often extend through long periods, and the Pliocene movements were in many places probably no more than continuations of movements begun in an earlier period, and continued into a later.

About the close of the Pliocene there seem to have been widespread crustal movements in most parts of North America. They resulted in increased height of land, and the time of active erosion which followed is sometimes known as the Ozarkian[4] or Sierran[5] period. In the east, the region overspread by the Lafayette formation was somewhat higher than now, and in reaching this position, it was perhaps somewhat deformed, though by no means all of the peculiarities of topographic distribution (p. 302) are to be ascribed to deformation, if the preceding explanation of the formation be correct. With the elevation of the coastal plain, the coast line was probably shifted

[1] Russell, National Geol. Mag., Vol. III, pp. 171–2.

[2] Dall, op. cit., and the Messrs. Arnold, Jour. of Geol., Vol. X, p. 125.

[3] LeConte, Jour. Sci., Vol. XXXII, p. 167, 1886, Bull. Geol. Soc. Am., Vol, II. p. 329, Jour. of Geol., Vol. VII, p. 546, 1899; Hershey, Science, Vol. III, p. 620, 1896; McGee, 12th Ann. Rept. U. S. Geol. Surv. and Science, Vol. III, p. 796; also King, op. cit., and Dutton, Mono. I, U. S. Geol. Surv.

[4] Hershey, Science, Vol. III. p. 620, 1896.

[5] LeConte, Jour. of Geol., Vol. VII, p. 529.

eastward, perhaps to the edge of the continental shelf, across which streams may have flowed, cutting valleys in its surface. To this epoch, the notable submerged continuations of the St. Lawrence, the Hudson, the Delaware, the Susquehanna, and the Mississippi are commonly referred. Some of these valleys have great depth, and it has been assumed that their depth was a measure of the elevation of the land at the time they were excavated. But if the considerations set forth in Chap. XX have force, it is not necessary to postulate such extraordinary changes of level by uplift and depression. Continental creep along the steep slope between the continental platforms and the oceanic basins may have depressed the valleys notably while it extended them seaward. The earlier assumption that the land along the Atlantic seaboard must have stood 2000 to 3000 feet, or perhaps even 7000 to 12000 feet,[1] above its present level, to allow of the excavation of these valleys, seems therefore unnecessary.

During the post-Lafayette interval of elevation and erosion along the Atlantic coast, much of the material of the mountain-ward edge of the Lafayette formation was shifted seaward, and redeposited along the lower courses of the streams.

In the Mississippi basin there was also notable elevation at this time. It seems possible, or perhaps even probable, that the evolution of the principal physiographic features of the interior, so far as due to erosion, began with the Ozarkian epoch, though the study of the evolution of the topography of this region has not advanced so far as to make this conclusion certain. The amount of uplift in this region at this time was probably less than has sometimes been estimated.

In the west, too, there were notable post-Tertiary movements. The plateau region was in process of uplift, periodically, throughout the Tertiary, during which it has been estimated to have undergone an elevation of 20,000 feet (Dutton), and a degradation of 12,000, leaving it 8000 feet above sea-level. How much of this is assignable to the Sierran epoch is uncertain. It was Dutton's view that the Colorado plateau was so elevated at this time as to rejuvenate the Colorado River, and that the cutting of its inner gorge some 3000 feet (maximum) below the outer (p. 275), was the work of later times. More

[1] LeConte, op. cit., and Spencer, Am. Jour. Sci., Vol. XIX, pp. 1–15, 1905.

recent studies indicate that even the outer and broader part of the valley, the esplanade, is younger[1] than was formerly thought, perhaps post-Sierran, and raise a question as to whether the inner gorge is not the topographic result of rock structure, rather than of a distinct and later uplift.[2] If the whole of the canyon is post-Sierran, the elevation of the region in the Sierran epoch (and later) must have been several thousand feet. The later elevations, largely by blocks, were so recent that the fault scarps are almost always ungraded and precipitous, and independent of stratigraphy and drainage.[3]

In the basin region, faulting and deformation were in progress,[4] and gave rise to two basins, one at the west base of the Wasatch mountains, and the other at the east base of the Sierras. These depressions prepared the way for two great Pleistocene lakes (Bonneville and Lahontan). It is probable that many other faults between the Rockies and Sierras were developed at the same time, and in many cases at least the movement seems to have been along fault planes established before the Pliocene period. Some idea of the great erosion which has affected the Uinta mountain region, since the Eocene at least, is gained from Figs. 462 and 463

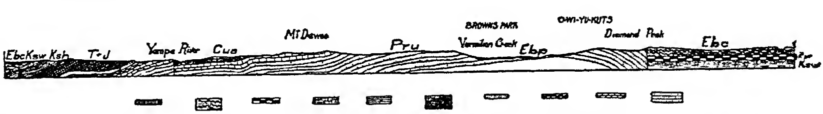


FIG. 462.—Section across the Uinta mountains. *Pru*, Uinta group Proterozoic (?); *Crw*, Lodore and Red Wall formations, the former probably Cambrian, the latter Mississippian; *Cla*, Lower Aubrey, and *Cua*, Upper Aubrey, are Carboniferous (Mississippian and Pennsylvanian); *T* and *J*, Triassic and Jurassic formations (Flaming Forge, White Cliff, Vermilion Cliff and Shinarump formations); *Ksl* (Sulphur Creek and Henry's Fork formations), *Ksw* (Salt-wells formation), and *Kpr* (Point of Rocks formation), Cretaceous; *Ebc* (Bitter Creek group) and *Ebp* (Brown's Park group), Eocene. (After Powell.)

In the Sierra region, the post-Tertiary (or late Tertiary?) uplift was still more marked.[5] The earliest Sierran folding of which the history is well known, was at the end of the Jurassic period.

[1] Huntington and Goldthwaite, Bull. Mus. Comp. Zool. Geol. Ser., Vol. VI, p. 252. While these authors do not state the time of the beginning of the canyon, they say that "the canyon cycle (of erosion) must include at least the later part of the glacial epoch."

[2] Davis, The Grand Canyon of the Colorado, Bull. Mus. Comp. Zool., Vol. XXXVIII.

[3] Huntington and Goldthwaite, p. 248.

[4] King, U. S. Geol. Expl of the 40th Parallel, Vol. I, p. 542.

[5] LeConte, op. cit., and Diller, 14th Ann. Rept. U. S. Geol. Surv.

"What kind of a mountain it was at that time, how high, and what its configuration, we know not; for the continuous erosion of the Cretaceous and Tertiary times had nearly swept it clean away. The cycle of its mountain life had reached its last stages. By continuous erosion it had been reduced to a peneplain, with its wide-sweeping curves of broad shallow channels and low-rounded divides. The rivers had reached their base-levels and rested. This was the work of the Cretaceous and Tertiary.

"Then came the post-Tertiary rejuvenation of the mountain life, by the formation of a fissure on the eastern slope, the heaving of the whole mountain block on its eastern side with a great eastern fault scarp; the transference of

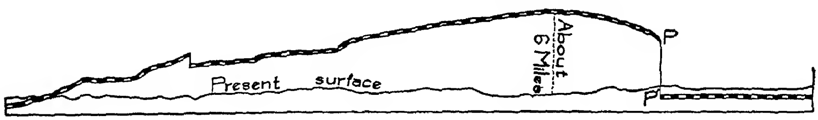


FIG. 463.—Represents the outline of the Point of Rocks formation of the last section, as it would have appeared without erosion, after faulting. The length of the section is about 57 miles. The vertical scale is the same as the horizontal. The displacement at *P* is nearly 20,000 feet. (After Powell.)

the crest to the extreme margin with great increase of the western slope and consequent revival of the erosive energy of the rivers. Coincident with this in middle California there was a great outpouring of lava, which ran in streams down the western slope, filling up the old river-beds, and displacing the rivers. The displaced rivers, with recently and fiercely aroused energy, immediately commenced cutting new channels, which are now 3000 to 6000 feet deep, and far below the old; so that these latter are left with their lava-covered gravels high up on the present divides. This was the work of the Ozarkian." [1]

Not only the deep canyons, but all the scenery of the high Sierras is post-Tertiary. "Its bold, rugged, savage grandeur is due to its extreme recency. The wildness of youth has not been tempered and mellowed by age."[2] It should be added that the beginning of the re-elevation of the Sierras, after peneplanation, is usually placed in late Miocene time.

Near the Pacific coast, too, notable changes marked the closing stages of the Pliocene and the transition from it to the Pleistocene. In some parts of southern California (Fort Frazer, Los Angeles County) marine Pliocene beds are said to occur up to altitudes of 6000 feet,[3] and in others (San Luis Obispo), there was folding (Fig. 444) and faulting at the close of the Pliocene, while the shore-line was pushed out

[1] LeConte, Jour. Geol., Vol. VII, p. 529–530.

[2] Le Conte, loc. cit., p 530.

[3] Hershey, Am Geol., Vol. 29, p. 364.

to near the edge of the continental shelf.[1] There was notable faulting in the Santa Cruz mountains of California at the end of the Pliocene, with uplift of the axis, while the flanks of the range remained submerged.[2] The wide-spread unconformity between the Pliocene and Pleistocene of the Pacific coast, is a further index of the great changes of the time.

There are submerged valleys[3] along the Pacific coast, as along the Atlantic, but their excavation, instead of following the Ozarkian uplift, is thought to have been the result of the post-Miocene movement which folded up the Coast range, and shifted the coast line west to the edge of the continental shelf. Some of them differ from the submerged valleys of the Atlantic coast, in not being the continuations of existing land valleys. The late Pliocene movements and lava flows, the latter filling many of the valleys, so disturbed the drainage that the streams no longer reached the sea at the same points as before.

In Washington, present knowledge seems to point to the early Pliocene as a time of prolonged erosion. The crests of the Cascade mountains seem to represent remnants of a deformed peneplain which, carried to the east and south, is continuous with an erosion plain, which cuts across strata (Ellensburg formation) of late Miocene[4] age. The planation must, therefore, have been later than that part of the Miocene period represented by the beds concerned. At least the early part of the Pliocene period, if not most of it, would seem to have been necessary for the accomplishment of this great planation, so that the peneplain can hardly be thought to antedate late Pliocene (Ozarkian) time. If this view be correct, the main features of the present topography of that most rugged region are the result primarily of late Pliocene and Pleistocene erosion on the peneplain which was uplifted and deformed in late Pliocene time, and secondarily of vulcanism, which has built up the great volcanic piles (Rainier and others) which affect the region.

In British Columbia also, the Pliocene is thought to have been primarily a time of erosion. According to the interpretation of those

[1] Fairbanks, San Luis folio, U. S. Geol. Surv.

[2] Ashley, Journal Geol., Vol III.

[3] LeConte, Bull. Geol. Soc. of Am., Vol. II, p. 325

[4] Smith, Ellensburg, Wash. folio, U. S. Geol. Surv.; also Willis and Smith, Professional Paper 19, U S. Geol. Surv.

who have studied this region, broad valleys, which have subsequently been elevated 2000 feet or more, were developed during the Pliocene. Near the close of the period there was further elevation in this region, and deep valleys were cut in the bottoms of the broad ones already in existence. These valleys were continued out across the continental shelf. Subsequent subsidence (and creep) has transformed part of the valleys developed at this time into fiords.[1] The valley lakes of this region occupy depressions which are thought to have been largely excavated at this time, and subsequently transformed into basins by warping, by glacial gouging, and by obstruction with glacial drift.

It will be seen that the interpretations which have been put on the phenomena in Washington and British Columbia are not altogether consistent. They would be brought into harmony if the broad valleys of the latter region, referred to the Pliocene, amounted to virtual peneplanation of the region concerned. The amount of post-Pliocene erosion in the Cascades, according to Smith and Willis, is much greater than that in the Grand Canyon region, according to Dutton's interpretation, but is more consistent with the later interpretations.

Deformative movements of the orogenic type seem not to have been common at the close of the Pliocene, but such movements affected the Santa Cruz mountains of California, where Miocene (Monterey) and Pliocene (Merced) beds were deformed together.[2] After the deformation the range is thought to have been 1000 to 1200 feet higher than now.

On the whole, the close of the Pliocene must be looked upon as a time of great crustal movement, a critical period in the history of North America. New lands were made by emergence from the sea, and old lands were deformed and made higher; new mountains were made, and old ones rejuvenated; streams were turned from their courses in some places, and nearly everywhere started on careers of increased activity. The Ozarkian epoch, the transition from the Tertiary to the Pleistocene, was, so far as North America is concerned, an epoch of great erosion. The fact that such notable changes, with increased elevation of land, occurred during the epoch next preceding the glacial period, led to a wide-spread belief that the elevation was the cause of the climate of the latter period; and while there may

[1] Dawson, Science, Vol. XIII, 1901, p 401

[2] Ashley, Jour. Geol., Vol. III, p. 434.

be a connection between them, it was probably not in the simple and commonly accepted sense.

The volcanic activity of preceding periods continued into the Plio-

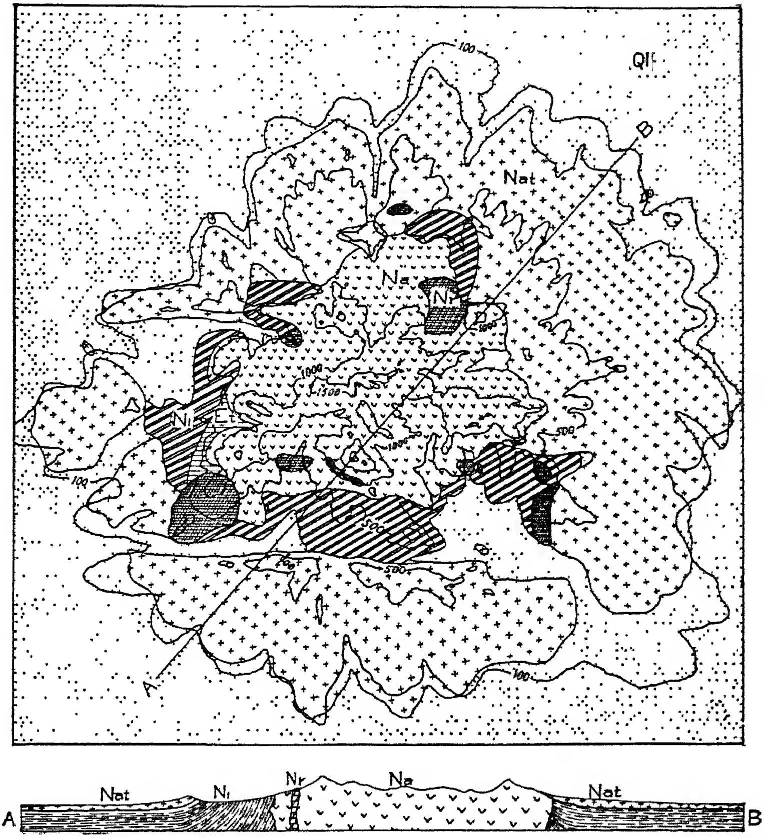


FIG. 464.—Map and section of the Marysville, Cal., volcano; *Et*, Eocene (Tejon formation); *Ni*, Miocene (Ione formation); *Ql*, Quaternary (river gravels); *Na*, andesite, *Nr*, rhyolite, and *Nat*, andesite tuff. Area of the map about 100 square miles. (Lindgren and Turner, Marysville, Cal. folio, U. S. Geol. Surv.)

cene, and became somewhat pronounced near the end of the period, in different parts of the Cordilleran system. Some of the late igneous formations of the Sierras, and perhaps of northern California,[1] belonged to this time, and probably some of those of nearly or quite every other state west of the Rocky mountains. Many of the prominent volcanic

[1] Hershey, Jour. of Geol., Vol. X, pp. 377–392.

peaks of the west date from this time, or later. The building of these cones appears to represent the later phase of the prolonged period of volcanic activity, just as the great lava flows and intrusions represent the earlier. Lesser cones in many places are probably to be referred to the same period.

Foreign.

From considerable areas of Europe covered by water during the Miocene, the waters retreated late in the period, or at its close. The sea still covered some parts of the continent, and at some points it extended itself at the expense of the land. Southern and southeastern England, Belgium, and perhaps a little of northern and parts of western France, were under water during at least some part of the Pliocene, but the submergence was not everywhere continuous from the Miocene, for the Pliocene sometimes (some parts of Belgium) rests with well-developed unconformity on Miocene and older beds. The sea covered much more extensive areas of the present continent about the Mediterranean, where parts of southern France (Rhone basin as far north as Lyons), Spain, Italy, Sicily, and Greece, were still submerged. Beyond the inland margins of the marine Pliocene, there are beds of lake or river origin. In southeastern Europe, brackish and salt lakes came into existence, as shown both by the fossils and the local deposits of salt and gypsum. In other places, sedimentary deposits were made in fresh lakes and river valleys, and in both, remnants of terrestrial life are found. Locally (Turkey), naphtha is said to be derived from the Pliocene.[1]

The beds deposited at this time show a culmination of the tendency to local variation characteristic of the Tertiary. This was the necessary result of the separation and isolation of the areas of deposition.

In England the lower part of the Pliocene is marine, and the upper part lacustrine, fluvial, and pluvial, as if the sedimentation shut out the sea. The system here attains a maximum thickness of between 100 and 200 feet. Here belong the beds known as Coralline Crag, Wealden Crag, Norwich Crag, Chillesford Crag, and Weyburn Crag, names applied to layers often no more than 10 feet in thickness.

[1] English, Q. J. G. S., 1902, p. 80, and 1904, p. 265.

In Belgium the thickness of the system is much greater, and consists chiefly of sand. In France the system contains volcanic material mingled with the sedimentary. The marine beds of southeastern France (Rhone basin) are unconformable on older rocks, and reach an elevation of 1150 feet. They extend up the valley of the Rhone, and their limit in this direction marks the northern limit of the depo-

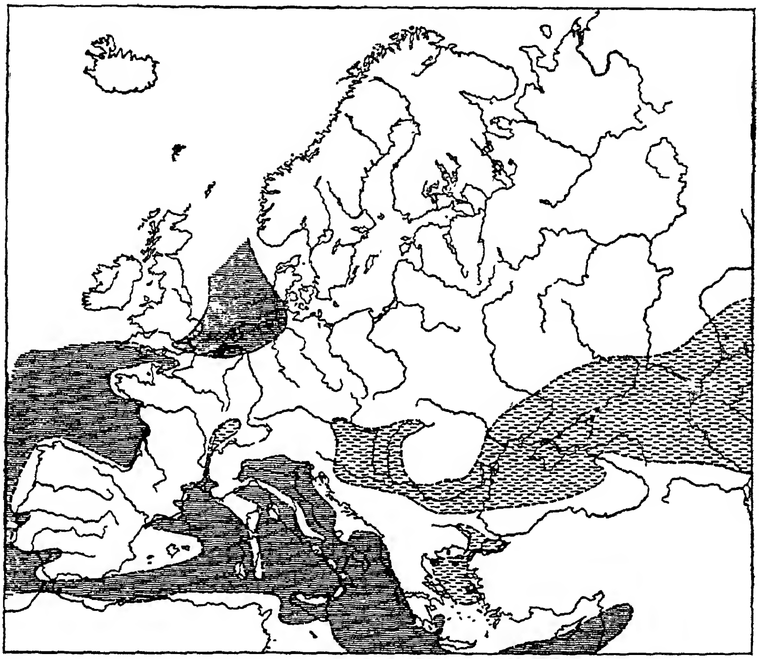


FIG. 465.—Sketch-map of Europe during the Pliocene period. The broken lines indicate areas of lacustrine and non-marine deposition. The full lines, the area of marine deposition. (After De Lapparent.)

sition in the southern Pliocene sea. The materials are largely unconsolidated.

Among the alluvial and lacustrine beds of the period, those of the basin of Mayence should be mentioned. They contain, along with the ordinary varieties of sediment, lignite, with plants of North American types. In the Vienna basin also are Pliocene deposits, brackish water beds below and fluvial beds above. In Italy only, do the Pliocene beds attain massive development. Along the Apennines, the system has been variously estimated at from 1600 to 3000 feet

in thickness, and in Sicily 2000 feet. Limestone as well as clastic beds enter into the system, and they occur up to heights of 3000 feet. Sedimentation was brought to an end by the movements which culminated in the outbreak of Vesuvius, Etna, and other Italian volcanoes. Etna at least, was first submarine, for its older tuffs are interstratified with marine beds. Later, by elevation, or by the upward growth of the volcanic cones, or both, the eruptions became subaërial.

Marine Pliocene is known in Egypt, where the sea is thought to have extended up the Nile to Assuan. The formation of the rifts of the Red Sea and the Gulf of Suez, has been assigned to the Pliocene period,[1] though the rift origin of these depressions has not been universally accepted.[2] Pliocene beds have also been reported from Tibet[3] (non-marine), India,[4] Borneo,[5] and the Philippines.[6]

The Life of the Pliocene.

The land plants.—The Pliocene was characterized by a still further sorting out of the mixed flora of previous periods, and by the southerly migration of what are now tropical and sub-tropical plants. Whether there was a northerly shifting of the opposite class of plants has not been determined. In southern France there were still some species identical with those now living in the Canaries. In Europe generally also, there was still much commingling of species that have since become geographically separated. Some of this was separation in longitude, and does not carry climatic suggestiveness. There were some genera that have since been driven eastward to the Caucasus, and some that are now characteristic types in North America, and so the flora had a somewhat American aspect. The tenor of available evidence, however, indicates not only a general differentiation, but a movement in latitude antecedent to the present distribution and adaptations of the plants. This has usually been interpreted as signifying a progressive refrigeration of the earth's climate, consonant with the conception of a progressive cooling of the globe, and an approach to a permanent condition of refrigeration; but other lines of evidence

[1] Barron and Hume, Geol. Mag., 1901, p. 156.

[2] Mennell, Geol. Mag., 1903, p. 548.

[3] Lydekker, Q. J. G. S., Vol. LVII, p. 292

[4] Oldham, Geology of India.

[5] Molengraaf, Geol. Expl. in Central Borneo, Rev. Geol. Mag., 1903, p. 170.

[6] Becker, 21st Ann. Rept. U. S. Geol. Surv., Pt. III.

do not altogether tally with this conception, and suggest rather that this was but one of the oscillations of climate that must now be recognized as marking geologic history. That the climate was becoming differentiated, and on the whole cooler than it had been in the earlier Tertiary periods, is clearly indicated.

The land animals.—The history of the mammals continued to be the one great center of interest. Three important features characterized it: (1) A notable intermigration of the continental faunas, including those of North and South America, (2) the initiation later of the present divergence between Old and New World types, and (3) the culmination and perhaps initial decline of the evolution of the placentals, the human and domestic species aside.

The accelerated intermigration of the early part of the period was a natural consequence of the extension of the land connections brought about by deformative movements. The precise nature of these land connections has not yet been worked out in all the details necessary to a satisfactory interpretation of the biological events of the period. There are outstanding problems as to the extent and continuity of the the connections between Eurasia and America at the northwest and at the northeast, but the evidence of good migratory routes for the land animals, during a portion of the period at least, may be accepted as conclusive. There are also strong hints of the progressive development of a selective bridge-and-barrier which afforded free passage for some species and shut off others, and this is assignable to increasing cold in the later stages of the period, leading up to the glacial period which followed. This was probably the chief influence in developing the divergence between the mammals of the Old and the New Worlds, for this divergence affects mainly the warm-latitude species.

The connection between North and South America introduced a biological movement of dramatic interest. There appears to have been no effective isthmian thoroughfare for land animals between the earliest Eocene and the Pliocene or thereabouts, when a way was opened. During the time of the Eocene connection a few mammalian types seem to have sent representatives into South America, and these had evolved on distinctive lines in the interval. A very remarkable group of sloths, armadillos, and ant-eaters had developed from an edentate stem: strange hoofed animals of orders unknown elsewhere (*Typotheria, Toxodontia, Litopterna*) had arisen from some very primi-

tive ungulate form; monkeys of the South American type had evolved probably from a North American Eocene lemuroid, while rodents of the porcupine type, but not of other orders, had been derived from some unknown immigrant form. That the connection was only partial or very temporary, seems to be implied by the absence of most of the great North American groups, such as the creodonts, carnivores, condylarths, artiodactyls, perissodactyls, and insectivores. The absence of proboscidians implies a lack of connection between South America and Africa, where these forms had been developing during the Eocene and Miocene. Many carnivorous and herbivorous marsupials closely similar to those of Australia lived during this interval in South America, implying either connection in that direction, or pronounced parallel evolution. If the former, it is unknown whether the migration was toward or from South America. This remarkable South American fauna is a striking instance of evolution on a large scale in comparative isolation, and in relative freedom from the severe stimulus of effective competition, powerful carnivores, and shifting geographic relations.[1]

On the opening of connection between the two Americas in Pliocene times, the faunas of each division invaded the other. Horses, mastodons, deer, carnivores of the dog and cat families, llamas, and tapirs from the north invaded South America, while certain gigantic sloths (*Megatherium*, *Mylodon*, *Megalonyx*, and *Glyptodon*) invaded North America. The latter group did not maintain themselves in North America beyond the Pleistocene period, whether because of the physical environment, the ice invasions, or the struggle with a superior fauna, cannot be affirmed. The northern invaders were more successful in South America though not conspicuously so, as only a portion of them have living descendants there.

That the extraordinary evolution of the undomesticated placentals experienced a decline at the close of this period was a natural result of the glacial invasions that followed, and of the even more potent influence of man.

During the period, the evolution of the mammals pursued essentially the same lines as before. The herbivores continued to occupy the foremost, as well as the fundamental place. Both the odd- and even-toed ungulates completed their deployment into all their present families,

[1] For late data see the Reports of the Princeton University expedition to Patagonia, 896–99.

and very generally into their present genera, and were also represented by many genera and numerous species which are now extinct. A list of Pliocene families would be little more than a catalogue of those now living. The evolution of the horse was advanced to the existing genus, *Equus*. The hornless rhinoceros continued in North America till near the close of the period, and then passed away. The horned branch flourished in the Old World, while the tapir disappeared from Europe. Giraffes and giraffe-like animals (*Samotherium*, *Helladotherium*, *Sivatherium*, *Bramatherium*, *Vishnutherium*), some of them of gigantic dimensions, invaded southern Europe and Asia, coming probably from Africa. The three last named have been found in the great Siwalik formation of India.

The giants of the period were the proboscidians. The *Dinotherium* may be regarded as an aberrant side branch that suffered the usual fate of such branches—early extinction. It was somewhat widely distributed in Europe and has been found in India, but is not known to have reached America. The mastodons seem to have occupied all the continents during the Pliocene, but it is doubtful whether the elephant reached the American continent before the Pleistocene. Some of the early mastodons had tusks in the lower as well as upper jaw (*Tetrabelodon*), but the most of the Pliocene species had tusks in the upper jaw only, in the adult state (*Dibelodon*). The mastodons were very closely related to the elephants, and are most conveniently distinguished by the teeth, the molars of the former being crowned by conical tubercles, while those of the latter are marked by transverse folds of enamel, separated by cement (Figs. 466 and 467). The elephants appear to have flourished abundantly in Europe, and with the associated rhinoceroses and hippopotamuses gave to the European fauna an African aspect.

The carnivores of both continents flourished and perhaps gained somewhat upon the herbivores; at any rate they put a severe tax on the herbivores, forcing still further adaptations in the line of alertness, sagacity, speed, and defense, and gaining similar qualities themselves. Besides most of the existing genera, the ferocious "saber-toothed tiger" (*Machærodus*) and some other extinct forms still existed. The rodents appear to have held about their present place relatively.

Supreme interest attaches to the development of the primates in this period, but as yet the data are limited and are likely to remain

so until the tropical regions of the Old World are more fully studied, for the chief evolution seems to have taken place there. No remains of lemuroids or of their descendants have been found in the Pliocene beds of North America. In Europe, all such remains thus far recovered

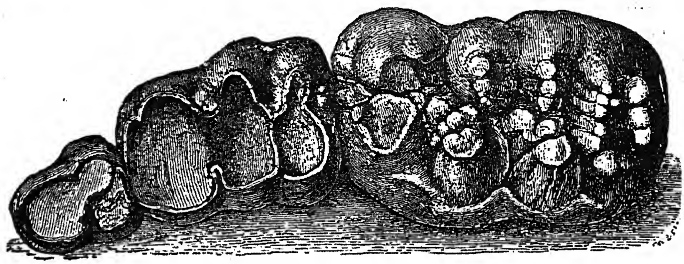


Fig. 466.—Teeth of mastodon (*Mastodon longirostris*), showing slightly worn tubercles at the right and much worn ones at the left. (From Gaudry, after Kaup.)

have been limited to the middle and southern portions, a limitation which is hardly accidental, and which probably implies that the climate of northern Europe was already becoming uncongenial to the primates. There are indeed signs of a gradual abandonment. The

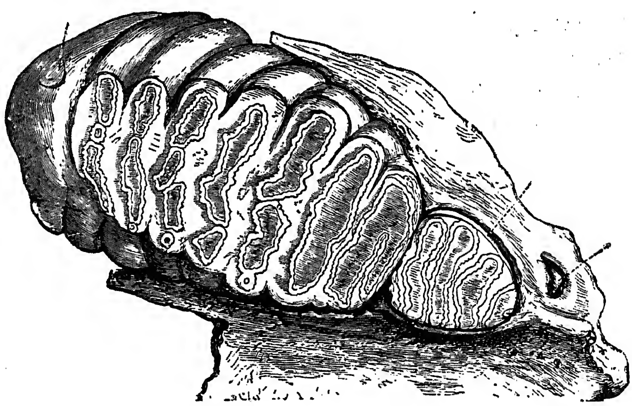


Fig. 467.—Teeth of elephant (*Elephus primigenius*), with the transverse ridges differentially worn, showing dentine in the center, the enamel, which forms the crenulated loops, supported by dentine within and cement without. (After Owen and Metcalfe.)

Paidopithex, a representative of the higher apes, seems to have left Europe in the earlier Pliocene. The lower apes (*Cercopithecidæ*) remained longer, and the *Macacus* (the Barbary ape) still lives on the rock of Gibraltar. The *Macacus* appears to have had considerable

range in Europe in the late Pliocene and early Pleistocene periods, and it is still the most widely distributed member of its family. The best known of the Pliocene tailed apes, the *Mesopithecus,* left abundant relics at Pikermi, near Athens. The *Mesopithecus* was closely related to the present Indian *Semnopithecus,* on the one hand, and to the *Macacus,* on the other. An allied genus, *Dolichopithecus,* which lived in France, is interesting on account of its large and long skull. The tropical

FIG. 467*a*.—Head of *Smilodon,*—a saber-toothed tiger. Outline restoration, showing the widely-gaping jaws. (After Knight.)

deposits will doubtless tell an interesting story of primate evolution when carefully studied.

Much the most interesting discovery of recent date is that of the remains of a man-like skeleton found near Trinil in Java and named *Pithecanthropus erectus.* The relics include the roof of a skull, two molar teeth, and an abnormal femur. The form of the last indicates that its possessor walked erect, in a sense that distinguished it from the apes. The forehead was low and the frontal ridge prominent, and in general the characteristic features were intermediate between those of the lowest men and of the highest apes, as shown in Fig. 468. The brain volume was about two thirds that of an average man. The interpretation of these remains has elicited much difference of opinion. By some they are thought to represent a dwarfed and diseased man;

by others, to belong to an ancestral type between man and his more remote ancestry, which is not supposed to be simian, but an independent phylum.

The marine life.—The record of American marine life on the Atlantic coast is extremely meager. During the larger part of the period the coast-line was probably farther out than it is now, and the record is inaccessible. The few forms found are very similar to those now

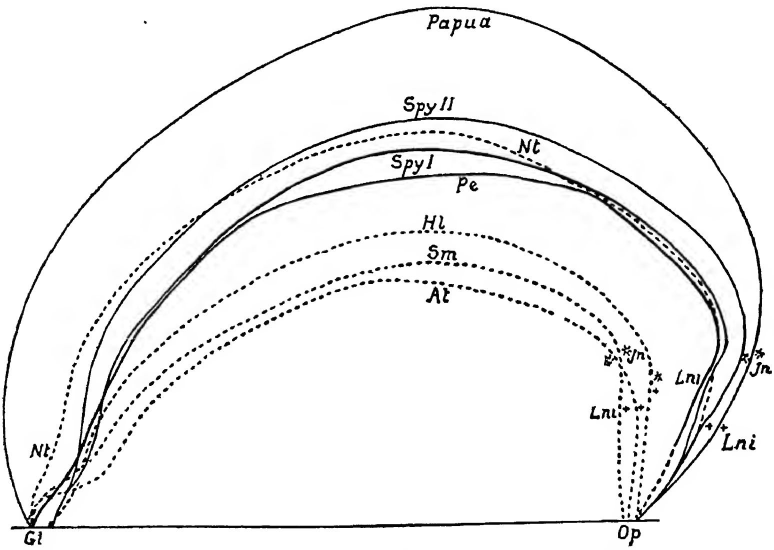


Fig. 468.—Profile of the skull of the *Pithecanthropus erectus* (line *Pe*), compared with profiles of the lowest men and highest apes: *Spy I* and *Spy II*, the men of Spy: *Nt*, the Neanderthal man; *Hl*, a gibbon (*Hylobates leuciscus*): *Sm*, an Indian ape (*Semnopithecus maurus*); and *At*, a chimpanzee (*Anthropopithecus troglodytes*). (After Marsh.)

living. On the Pacific coast there is a better representation,[1] but even this probably represents only a small portion of the period, and it is not certain which portion this is. The fauna is very similar to that now living in the waters off shore. As recorded at San Pedro, it has many species (18.5%, Arnold) now found living only at points farther north, and most of the other species are now more abundant to the north. This has led to the inference that the climate was then somewhat colder than now. As in previous periods, the gastropods and pelecypods greatly predominated.

[1] Mem. Cal. Acad. Sci., Vol. III, 1903, Ralph Arnold.

CHAPTER XIX.

THE PLEISTOCENE OR GLACIAL PERIOD.

THOUGH it derives its systematic name from the fact that its life constitutes the closing stage of the transition from the great past to the present, the distinguishing feature of the Pleistocene period is its phenomenal glaciation. Ice-sheets spread over six or eight million square miles of the earth's surface where not long before mild climates had prevailed. Were it not for this great ice deployment, and for its profound effects on the conditions under which man has developed, this period would more properly be joined to the Pliocene, the two constituting a single period of great land relief and oceanic restriction. The time assigned the Pleistocene is much shorter than that of the average geologic period. It appears that the later periods, as a rule, are shorter than the earlier ones, due to our magnifying the importance of events that are near to us. The Pleistocene expresses this more markedly, perhaps, than any other period. The importance of the Pleistocene period has, however, been greatly increased by recent investigations, not only in respect to its length, but also in respect to its diversity and its bearing on human evolution.

General Distribution of the Glaciation.

More than half of the area of the Pleistocene glaciation lay in North America, and more than half of the remainder lay in Europe. The glaciation was, therefore, pronouncedly localized, as was that of the Permian period, and probably also that of the still earlier Cambrian or pre-Cambrian. But the whole world felt its effects; even in the tropical regions, glaciation occurred on mountains where it did not exist before and does not now exist, and on mountains now glaciated the ice descended to levels 5000 feet or more below its present limit.

The southern hemisphere was affected as well as the northern,

but to a much less degree. In Patagonia and New Zealand, glaciers crept down from the mountains and spread out on the lowlands to notable extents. Glaciers formed on the mountainous tracts of Tasmania and Australia where none exist now. The higher mountains of the southern hemisphere generally bore glaciers even in low latitudes. Antarctica was presumably buried beneath ice as now, but this is purely a matter of inference. Notable as was this glaciation of the southern hemisphere, it was insignificant compared with the deployment of ice in the northern hemisphere.

In Asia, ice fields much greater than those of the present time affected the higher mountains. Though its extent is but partially known, former glacial work has been recognized at various points from the Lebanon and Caucasus mountains in the southwest, eastward along the high ranges to the Himalayas and the high mountains of China, and northward to the ranges of eastern Siberia. On the plateaus and lowlands of Asia, ice-sheets were far less extensive than in Europe and North America. It has been both affirmed and denied that the Mongolian plateau was glaciated. The northern border of Siberia in the region of the Taimur peninsula, and again in the far northeast, was covered with ice, and glaciers descended from the northern Urals to the plains of the Obi. With the exception of a portion of the Siberian tract, all the Asian glaciation was associated with high altitudes.

In Europe, there were large glaciers in the southern mountains and extensive ice-sheets on the northwestern plains. Radiating from the Scandinavian highlands, a succession of great ice-sheets crept forth upon the lowlands of Russia, Germany, Denmark, Holland, and Belgium, and, apparently crossing the shallow basin of the North Sea, touched the shores of England and Scotland, where they were met by ice radiating from the mountains of Great Britain (Fig. 528). From the Alps, gigantic glaciers descended to the lowlands in all directions. Thus the Rhone glacier moved out far beyond the mountains, and became confluent with glaciers from the mountains of Savoy and Dauphiny, on the plains of France;[1] while from the southern Alps, glaciers descended to the plains of Italy. Glaciers of similar dimensions descended into the valleys of the Rhine and the Danube. The Pyrenees, some of the higher mountains of the Spanish plateau, the

[1] Geikie, J., Outlines of Geology, p. 373.

higher mountains of France, the Apennines, the Carpathians, the Balkans, the Caucasus and the Urals, all had their glaciers, while from the northern Ural and Timan mountains ice-sheets descended into the basin of the Pechora. Iceland and the Faroe Islands were buried

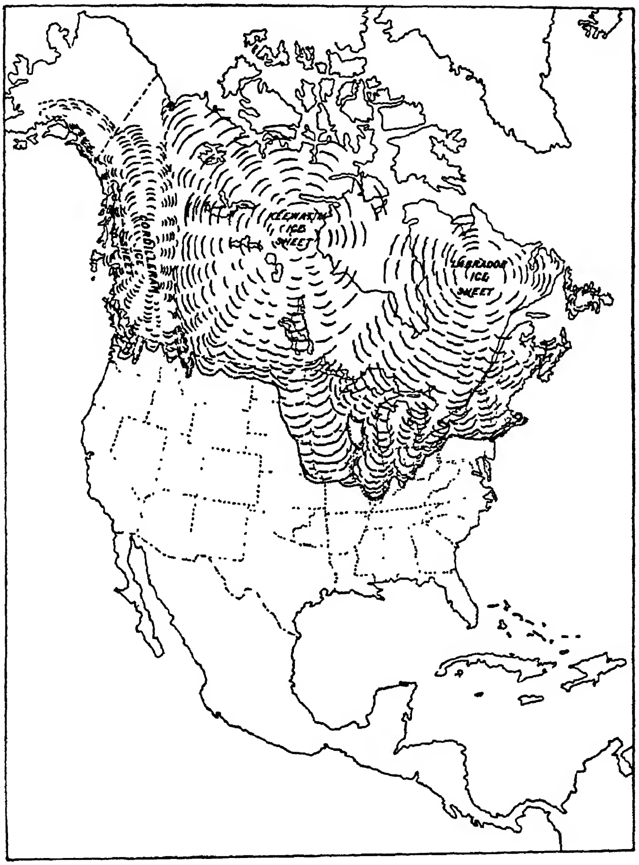


FIG. 469.—Sketch-map showing the North American area covered by ice at the maximum stage of glaciation.

in ice, and even Corsica had snow-fields and glaciers, some of which were not diminutive.

Nearly one half of North America was buried in ice (Fig. 469). Strangely enough, it was not strictly the northern half, but the north-eastern half, that was specially ice-invaded, and, more strangely still,

not so much the mountainous portions, though these were affected, as the plains. Alaska was largely free from ice except on or about the mountains, and continuous glaciation did not extend as far south on the mountain-girt plateaus of the Pacific border as on the smooth, low plains of the Mississippi valley. Much the greater part of the 4,000,000 square miles of the ice-fields lay on the plains of Canada and in the upper Mississippi valley. The Missouri and Ohio rivers, like two great arms, embraced the borders of the greatest of the ice-sheets to which they owe their origin. The special features of this predominant glaciation first invite our attention.

The Glaciation of North America.

The centers of glacial radiation.—In North America, three great centers of glacial radiation, besides Greenland, have been recognized. These are the Labradorean, the Keewatin, and the Cordilleran. From these centers, ice-sheets spread forth covering some 4,000,000 square miles (Fig. 469). The centers from which the last radiations of ice took place are determined with certainty by glacial striation and by the lines of transportation of drift. The centers of the earlier radiations of ice, where overridden by the last, are less positively known, but no serious misconception is likely to be gained, if the centers of dispersion in the late glacial epochs are regarded as the centers in all. These centers are indicated in Fig. 470, where the lines of movement, the extension in different directions, and the configuration of the borders at certain stages are indicated. From this map it will be seen that the radiation was unsymmetrical in all cases, being greatest southward, southwestward, and westward.

From the Labradorean center, the extension was notably greatest to the southwest, in which direction the limit is only found some 1600 miles from the center of dispersion. This limit lies in about 37° 30′ latitude, and is the most southerly point of the great lowland glaciation of the period. The extension of the Keewatin ice-sheet to the southward was scarcely less great, finding its limit in Kansas and Missouri, about 1500 miles from its center, while to the west and southwest it extended 800 to 1000 miles toward the foot-hills of the Rocky Mountains.

The details of ice movement northward from these two centers are not well known, but the fact of general northward movement is estab-

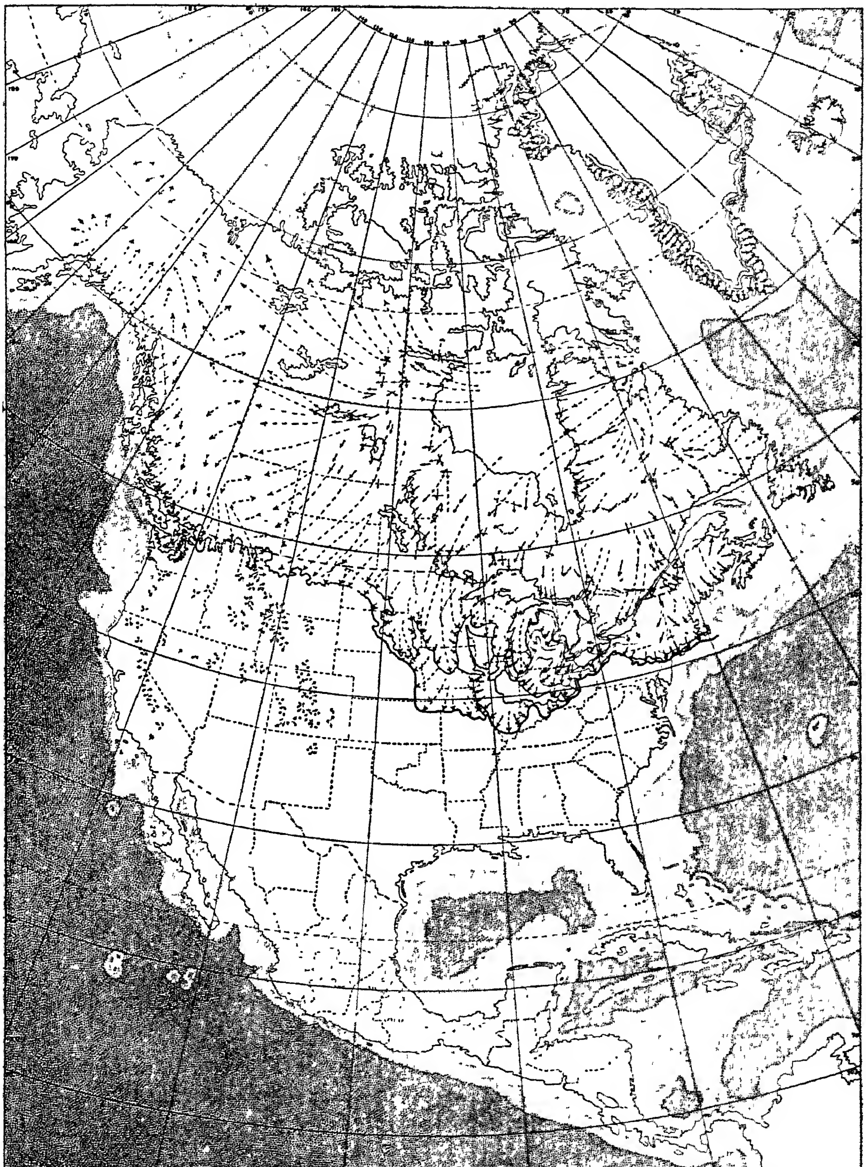


FIG. 470.—Map showing the glaciated area of North America. The heavy line across the United States represents the limit of glaciation. The lobate outline of the ice of some of the later stages is also shown. The arrows back from the edges of the drift-sheets indicate direction of ice movement, as recorded by striæ. The dotted lines represent direction of movement generalized from the recorded striæ. They radiate from the three centers indicated in the text. The short arrows in the western part of the United States indicate the general distribution and direction of movement of the ice in that part of the continent. There were doubtless glaciers in some areas where they are not represented.

lished. The Keewatin sheet pushed northwestward to the mouth of the Mackenzie, and probably to Banks Land, northward and northeastward to the Arctic Islands,[1] and eastward to Hudson Bay, and into confluence with the Labradorean sheet. The latter pushed northward into Ungava Bay, eastward into the North Atlantic, and southeastward into the Gulf of St. Lawrence.

One of the most marvelous features of the ice dispersion was the pushing out of the Keewatin sheet from a low flat center, without even a suggestion of a mountainous nucleus, 800 to 1000 miles westward and southwestward over what is now a rising and semi-arid plain, while the mountain glaciation on the west, where now known, pushed eastward but little beyond the foothills.

There were probably some important variations from the present altitudes which influenced the spread of the ice. The western region was probably relatively lower, and the eastern relatively higher than now; and while there is no question but that topography is an influential factor in controlling the movement of glacial ice, it is probable that differences of precipitation on the different sides of the ice-sheets, and the consequent differences of topography of the ice-surface were still more important. Differences in the mobility of the ice, due to differences of temperature were also probably effective. In general, it is probable that the factors of growth and mobility take precedence over the topography of the bed in determining the course of movement where thick and extensive bodies of ice are involved, for they not only determine the distribution of the material that is to move, but they develop an ice topography, and sometimes a quasi-fluency, which may become the controlling factors in the movement.

The Cordilleran ice-sheet[2] is less simply defined. Much of it occupied a plateau hemmed in by mountains, and plateau glaciation was complicated by extensive mountain glaciation of alpine type. In some sense, the whole Cordilleran ice-sheet was the product of a confluence of mountain glaciers deploying on the intervening plateau but there appears to have been plateau glaciation not solely dependent on contributions of ice from the mountains. The southerly lobes o

[1] Dawson, G. M., Ann. Rept. Geol. Surv. of Can , Vol. II, 1886, pp 56–58 R.

[2] Dawson, Ann. Geol., Vol. VI, p. 162, Geol. Surv. of Can., 1888, and Trans Roy. Soc. of Can., Vol VIII, Sec. IV; Tyrrell, Geol. Surv. of Can., 1890, E, pp. 1–240 and McConnell, idem, D, pp. 24–28.

the complex body of ice crossed the boundary of Canada, and encroached somewhat on the United States in the Flathead, Kootenay, Columbia Okanagon, and Colville valleys. The northern lobes descended the valleys tributary to the Yukon, but, so far as now known, did not cross the Canadian boundary into Alaska. It is not known that the Cordilleran plateau glacier escaped the Rockies to the east, or even sent tongues through their gaps in the more southerly latitudes of Canada, though glaciers formed on the mountains crept out on the western borders of the plains. In the more northerly uninvestigated latitudes, where the mountains are lower and the gaps deeper and broader, the descent of ice from the plateau on the west to the plains on the east is not improbable. On the west, the plateau ice-cap seems to have sent tongues of ice through the gaps in the coast ranges at many, points, and to have discharged thence into the Pacific. Though hampered by its environment, the Cordilleran ice-sheet seems to have conformed to the habit of the Larbradorean and Keewatin sheets in expanding chiefly to windward. If the whole glaciation, plateau and alpine, be regarded together, the westward movement of the Cordilleran complex was perhaps even more pronounced than that of the Keewatin and Labradorean.

Mountain Glaciation.—In Alaska, mountain glaciation was strongly developed on the ranges adjacent to the Pacific, particularly on the side next to the ocean. On the north side, the ice pushed well out from the higher mountains, but did not reach the Yukon. Some ancient glaciation has recently been discovered on the divide between the Yukon and the Arctic Ocean, but with this, and perhaps some undiscovered exceptions, the plains of Alaska seem to have been free from glaciation even at the stages when the waters of the Ohio and the Missouri were being turned from their courses by encroaching ice-sheets, 2000 miles farther south. In view of these and other singular features of distribution, the localization of the ancient glaciation becomes one of its most significant problems.

South of the continuous Cordilleran glaciation of Canada, local glaciers were widely distributed from the Rockies on the east to the Sierras and Olympics on the west, while on the south, within the United States, they appeared in New Mexico, Arizona, and southern California. Within this broad area, the deployment of ice was greatest at the north. Of glaciation in the mountains of Mexico little is known.

The ice of the Puget Sound region [1] came from three sources: the smallest part came from the Olympics on the west; another and larger part from the Cascades to the east, while the third and largest part came from the north. This northern glacier sent a branch westward into the strait of Juan de Fuca, as well as one south into Puget Sound. The southern edge of this Puget ice sheet lay south of Tacoma and Olympia.

East of the Cascades also, glaciation was extensive. As already noted great tongues of ice, altogether beyond the size of valley glaciers, descended from the north into the basins of the Okanagon, the Columbia, and the Colville Rivers.[2] Glaciation was also widespread in northern Idaho and northwestern Montana. From the Rocky mountains of the latter state, mountain glaciers descended and spread for miles on the plain to the east. Just south of the national boundary, the drift from the Keewatin ice-sheet overlaps that from the mountains.[3] Farther south, the extension of the ice east of the mountains was less. Although they have not all been well studied, it is safe to say that all the principal mountains of Montana, Wyoming, Idaho, Oregon, and Washington harbored glaciers, some of which were very large. In the Yellowstone Park, in the eastern part of the mountains, glaciation was so extensive as to belong to the ice sheet, rather than the valley glacier type. The aggregate number of glaciers which existed in these northwestern states has never been determined, but it must have risen into the thousands.

The glaciers of the Bighorn mountains of Wyoming [4] (Fig. 471) were perhaps typical for those of the lesser ranges in this section of the United States. The glaciers of this range were numerous, the longest being about 17 miles in length. None of them, however, reached the surrounding plains.

Farther south, in Colorado, the Front range [5] was more or less generally glaciated for a width of 16 miles in latitude 40°, while the Park range was glaciated somewhat generally over an area 60 miles long by 10 miles wide. Glaciation in the Medicine Bow range was less extensive. On the east side of the Sawatch range, an elevation of about 11,000 feet was necessary to produce glaciers.[6] Glaciers of great size (one 65 or 70 miles long) existed in the mountains of southwestern Colorado, where their sources were at altitudes of 11,000 feet or more.[7] In no part of Colorado thus far studied does there appear to have been a body of ice which extended beyond the limits of a single drainage system.

South of the Front range of Colorado, the eastern ranges of the Rockies were the site of numerous glaciers as far south as northern New Mexico [8] (lat. 35° 45′),

[1] Willis, Tacoma folio, U. S. Geol. Survey.

[2] Blackwelder and Garrey, Jour. of Geol., Vol. IX, pp. 721–724.

[3] Calhoun, Jour. of Geol, Vol. IX, p. 718.

[4] Blackwelder, Jour. of Geol., Vol. XI, p. 216.

[5] King, Geol. Surv. of the 40th Parallel, Vol. I.

[6] Leffingwell and Capps, Jour. of Geol., Vol. XII, p. 698.

[7] Stone, Mono. XXXVII, U. S. Geol. Surv.; also Hole and Everley, unpublished data.

[8] Salisbury, Jour. of Geol., Vol. IX, 1901

where an altitude of nearly 12,000 feet was necessary to give origin to them. There were also small glaciers on the northeast slope of the San Francisco moun-

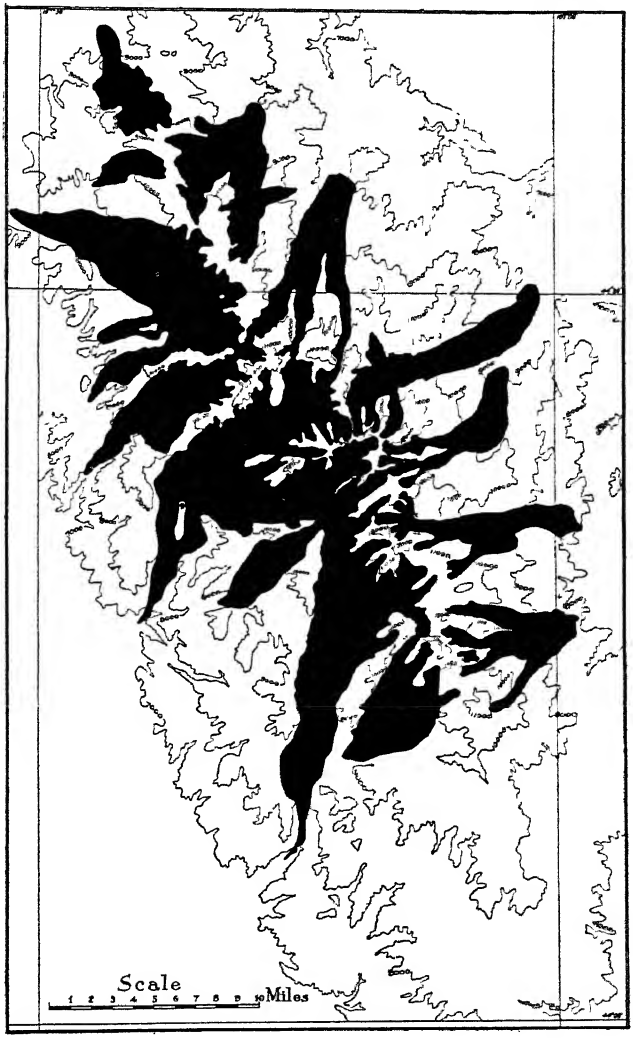


FIG. 471.—Map showing the areas of the glaciers (black areas) of the Bighorn mountains during the last important glacial epoch. (Blackwelder and Bastin.)

tain of Arizona (nearly 13,000 feet, lat. 35° 21′), the most southerly point where glaciers are known to have existed in the United States.[1]

[1] Atwood, Jour. of Geol., Vol. XIII, p 276.

In Utah, the greatest glaciers were in the Uinta mountains, where within an area about 80 miles long by 35 miles wide, there was an aggregate area of about 1000 square miles of glacier ice.[1] Near the crest of the range, only narrow divides with steep slopes escaped glaciation. Every considerable valley of the range whose head had an elevation of 10,000 feet, contained a glacier. In a few cases, the glaciers descended below the mountains into the open valleys of the plateau below. The lowest altitude reached by any glacier in the range was about 6500 feet, and the ice descended on the average about 1000 feet lower on the south side than on the north, primarily because the catchment basins on the south slope were larger. Individual glaciers attained a thickness of some 2500 feet. Glaciation was less extensive in the Wasatch mountains, though the number of glaciers there exceeded 50. The ice was still more limited in the Bear River mountains of Idaho, just north of the Wasatch range.

Glaciation was of slight extent in the basin ranges of Nevada, though there were several centers of glaciation among the higher ranges.

There were extensive glaciers in the Sierras. Under favorable conditions, they descended to an altitude of 4500 feet, and at a few points even lower.[2] In few other places in the west were conditions so favorable either for heavy snowfall or for ready descent of the ice to low altitudes.

These isolated areas of glaciation are instructive as indicating the extension of the requisite conditions beyond the limits of the great continental ice-sheets. If, however, the plains have been elevated since, as the distribution of the Keewatin ice and some other facts suggest, the altitude both of the eastern mountains of the Cordilleran system, such as the Bighorns, and of the limits of glaciation, were probably lower than now at the time of glaciation.

In Wyoming, Colorado, Utah, California, and Washington, the only places where the glacial history of the western mountains has been studied in detail the drift is referable to two or more glacial epochs, somewhat widely separated in time.

Island glaciation.—The Island of Newfoundland seems to have been a separate area of glaciation. The same was probably true of Nova Scotia, and evidence is presented by Canadian geologists that the elevated peninsula between the Bay of Fundy and the lower St. Lawrence shed ice northward and eastward as well as southward.[3] Greenland was glaciated somewhat more extensively than now, but its glaciers appear never to have extended to the continent, as was formerly conjectured. A little driftless region in the Inglefield Gulf

[1] Atwood, unpublished data; also King, Geol. Surv. of 40th Parallel, Vol. I

[2] California folios, U. S. Geol. Surv.

[3] Dawson, J. W. The Canadian Ice Age; Chalmers, Can. Rec. of Sci., 1899, and Rept. Geol. Surv. of Can., 1885; Murray, Geology of Newfoundland.

region,[1] and consonant phenomena elsewhere, indicate only a limited extension of the ice beyond its present border. The Arctic islands west of Greenland seem, from present evidence, to have been only partially glaciated, though the ice extended considerably beyond its present limits.

Summary.—Reviewing comprehensively the distribution of the ice, it appears that by far the greatest Pleistocene glaciation was developed in the northern hemisphere, and that its most significant portion was the glaciation of the great lowland areas of northeastern North America. This glaciation reached its climax of significance in the deployment of the Keewatin ice-sheet from a low, flat center, in seeming, but doubtless not real, negligence, or even defiance of topographic relations, and to some extent of climatic conditions as well.

The Criteria of Glaciation.

So extraordinary a series of phenomena as the repeated burial of half the plains of North America beneath sheets of ice which spread southward into mild temperate latitudes, could not be accepted on other than the most cogent evidence, and it is not strange that the glacial theory was resisted for half a century, though the iceberg and other glacio-natant hypotheses urged in its stead seem no more credible, and far less adequate. But the cumulative force of a vast mass of evidence, rigorously scrutinized under the promptings of this critical and reluctant attitude, has become overwhelming, and the days of reasonable doubt are passed. The decisive evidence lies not only in a great mass of individual criteria, but in a combination of convergent lines of proof which lend invincible support to one another.

The area which was overspread by ice is covered by a mantle of clay, sand, and bowlders, which, taken together, constitute *the drift*. Some of the drift is stratified (Fig. 472), but more of it is without the assortment and the definite arrangement which goes with stratification (Fig. 473). The various lines of evidence which have led to the general acceptance of the glacial theory, have to do with (1) the drift, (2) the surface of the rock which underlies it, and (3) the relations of the drift to its bed. Some of the principal considerations are the following:[2]

[1] Chamberlin, Jour. of Geol., Vol. III, 1895.

[2] The phenomena pointing to the glacial origin of the drift have become so fa-

(1) **The constitution of the drift.** — One of the striking characteristics of the drift, taken as a whole, is its heterogeneity, both physical and lithological. It is made up, at one extreme, of huge bowlders (Figs. 474 and 475), and at the other of impalpable earthy matter. Between these extremes there are materials of all sizes, and the proportions of coarse and fine are subject to the greatest variations. Coarse materials are, on the whole, most abundant in regions of rough topography where the underlying formations are resistant, and in the lee

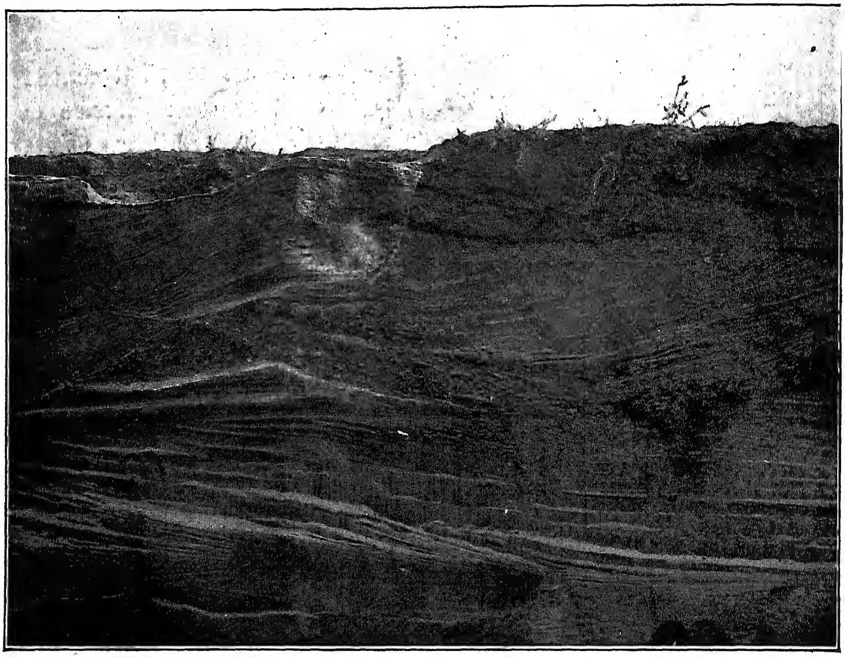


FIG. 472.—A section of stratified drift.

of such situations. Fine materials, on the other hand, are most abundant where the underlying formations, and especially the neighboring formations in the direction whence the ice came, are weak. The

miliar that it is unnecessary to give extended references to the literature of the subject. They were emphasized in many of the early publications concerning the drift, The striæ and other scorings of the ice, are elaborated in the 5th Ann. Rept. U. S. Geol. Surv. The study of the drift from the standpoint of genesis is given in the Jour. of Geol., Vol. II, pp. 708–724, and 837–851, and Vol. III, pp. 70–97, and in Glacial Geology of New Jersey, pp. 3–33. The geological reports of all the states affected and of Canada contain descriptions of the phenomena.

fine material of the drift is made up, in large part, of the same materials as the gravel and bowlders, but of these materials in a finer state of subdivision, and often in different proportions. The coarse materials and the fine are often mixed without trace of assortment or arrangement.

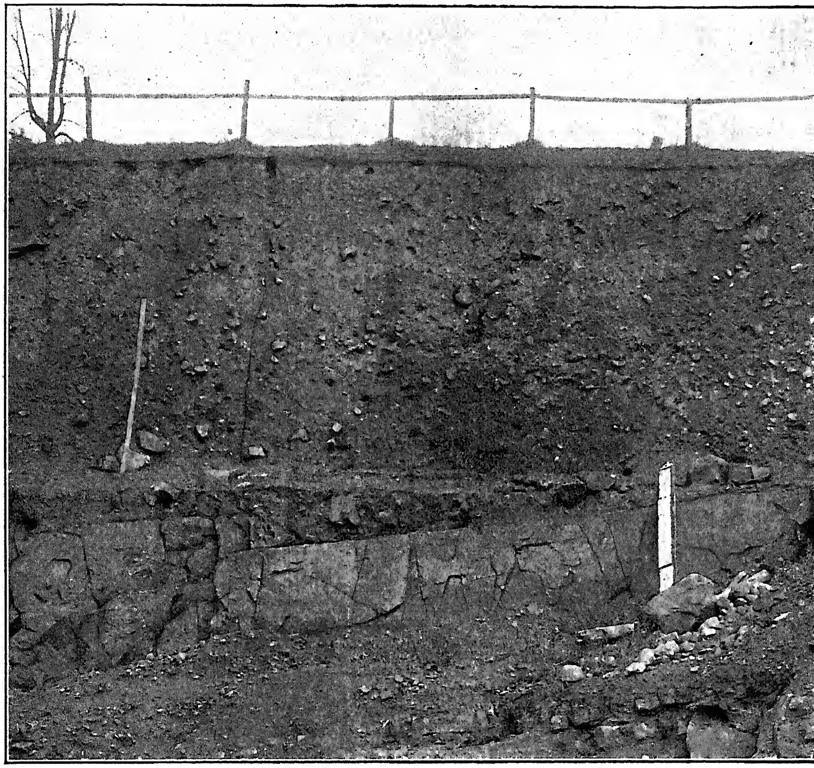


FIG. 473.—A section of unstratified drift—till or bowlder clay, on bed-rock. Newark, N. J.

The drift of any locality is likely to contain rock material from every formation over which the ice which reached that locality had passed; but the larger part of the drift of any place is composed of materials derived from formations near at hand. Probably 75% of the material of the drift has on the average not been moved 50 miles.[1]

No agent except glacial ice can impress these precise features on

[1] The Local Origin of the Drift, Jour. of Geol., Vol. VIII, p. 426.

the deposits which it makes, and these are, on the other hand, precisely the features which existing glaciers are now impressing on their deposits.

(2) **The bowlders and other stones of the drift.**—The bowlders and smaller stones of the unstratified drift possess significant features. Many of them have smooth surfaces, but they are not

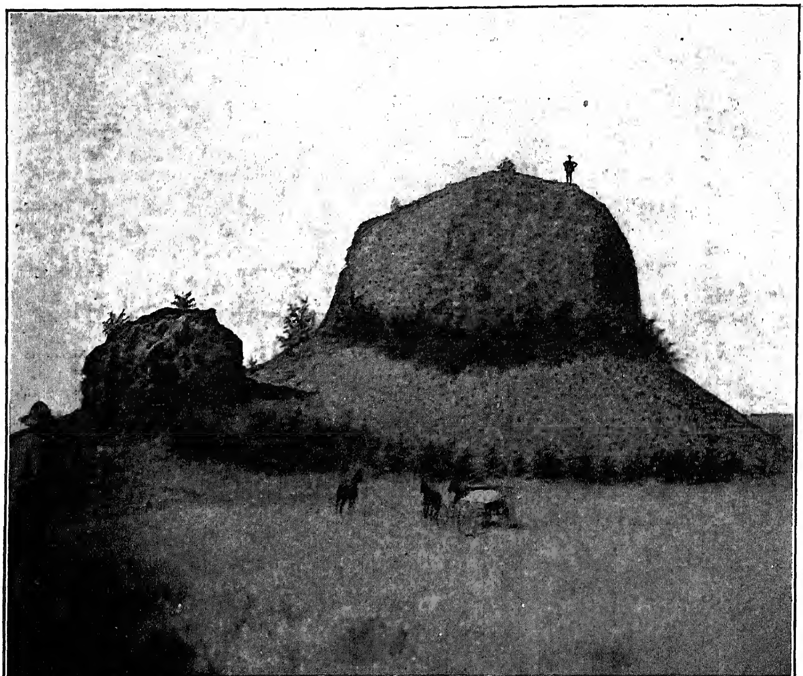


Fig. 474.—"Pilot Rock." A bowlder of basalt near Coulé City, Washington. One of the largest bowlders in America. (Garrey.)

generally rounded. They are often sub-angular, and the wear which they have suffered has been effected by planing and bruising, rather than by rolling (Fig. 254, Vol. I, and Figs. 476 and 477). The plane sides meet one another at various angles, though the angle of junction is rarely acute. These planed, sub-angular bowlders and stones are often distinctly marked with one or more series of lines or scratches, on one or more of their faces. The lines of each series are parallel, but those of different series may cross at any angle.

By no means all the stones of the drift show striæ. They are rarely

seen on those which have lain long at the surface, and they are much more common on the less resistant sorts of rock, such as limestone, than on more resistant ones, such as quartzite. Locally, distinctly striated stones are rare even in the unstratified drift, and they are generally rare on the rock fragments of the stratified drift.

No depositing agent except glaciers habitually marks the stones

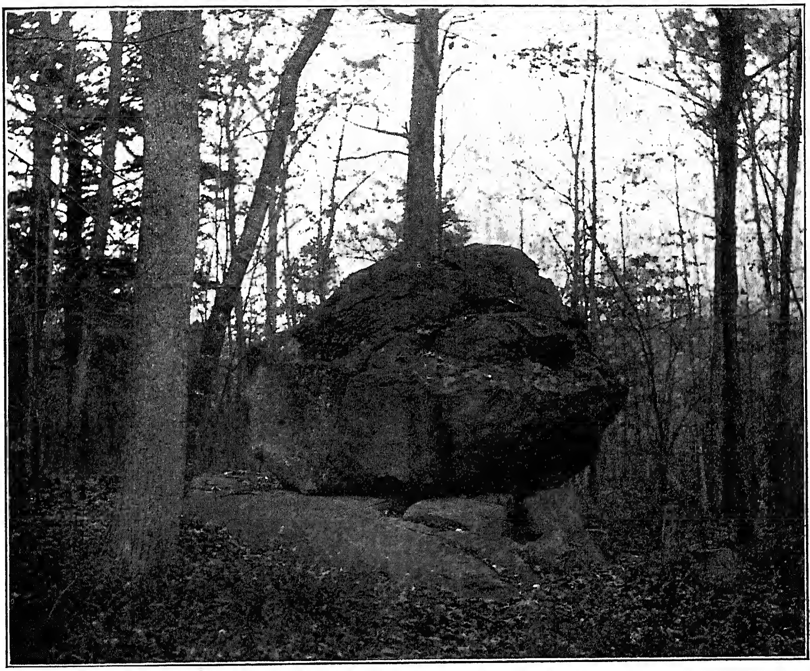


Fig. 475.—A perched bowlder of Triassic sandstone on the trap-rock of the Palisade ridge east of Englewood, N. J. Size 12×8×8 feet. This bowlder was probably carried up by the ice something like 200 feet. (N. J. Geol. Surv.)

which it deposits in this way. Bowlders dropped by icebergs sometimes have such markings, but icebergs are born of glaciers, and the marks of the striated stones of icebergs were put upon them while they were still in, or under, the land ice. Water never striates stones in this way.

(3) **Structure of the drift.**—The larger part of the drift is unstratified, but a very considerable part is stratified, often irregularly. The unstratified drift or *till* (for some of it the name bowlder-clay is appro-

priate), seems to have little orderly arrangement of its parts, yet it often has a sort of rude cleavage which has been called *foliation.*

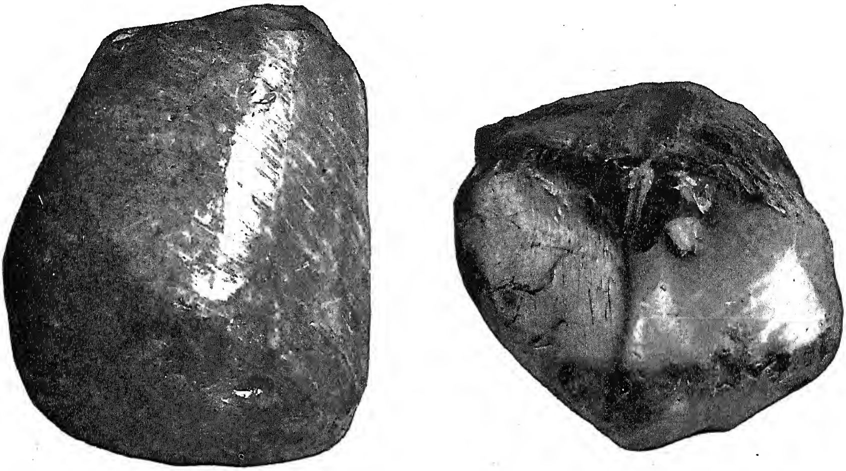


FIG. 476.—Glaciated stones from the drift of northern Illinois. (Photo. by Church.)

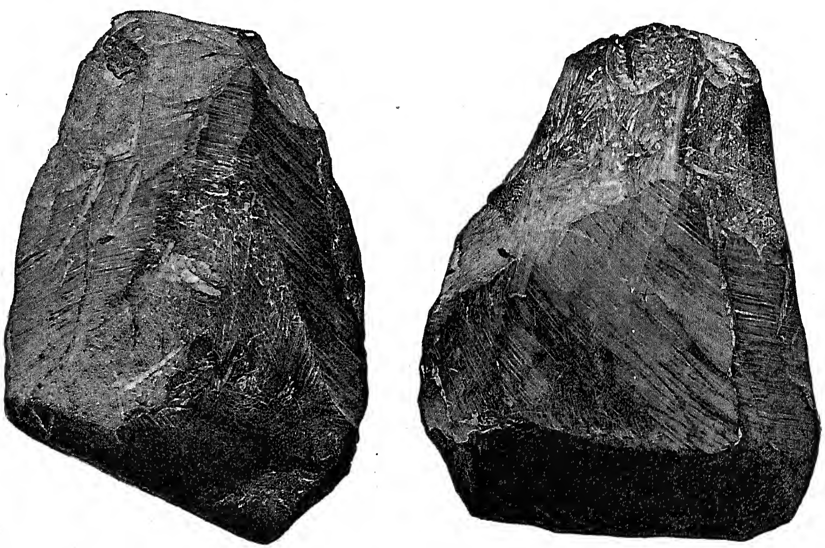


FIG. 477.—Glacially faceted and scratched pebbles, remarkable for the number of planed faces, for the pronounced beveling, etc.; from the Illinois and Michigan canal, Chicago.

The planes of cleavage are in such relations as to suggest that they were developed by pressure from above. This is consistent with the

deposition of the foliated drift beneath a body of ice. The stratified drift shows by its structure that it was deposited by water. This water doubtless sprang, very largely, from the melting of the ice.

The structural relations of the two great types of drift will be referred to again, but a conception of these relations is necessary to an understanding of the structure of the drift as a whole. Either type of the drift may overlie the other, or the two may be interbedded; either may grade laterally into the other, either may abut abruptly against the other horizontally, or pockets of either may be enclosed in the other.

The association of the two is often such as to demonstrate their essential contemporaneity of origin. No agents but glacial ice and glacio-fluvial waters could have brought about such relations between the stratified and unstratified drift over such extensive areas.

(4) **Distribution of drift.**—The distribution of the drift is essentially the same as that of the ice-sheets and glacial waters; but apart from this general fact, there are several special features to be noted. (*a*) The distribution of the drift is measurably independent of topography within the area of its occurrence. Even in closely associated localities, and outside the higher mountain areas, its vertical range is as great as the relief of the surface itself. Within the limits of the state of New York, for example, it ranges from sea-level to the tops of the Adirondacks, nearly 5000 feet above. Within the area of its occurrence it is generally found in valleys and on hills, and on plains, plateaus, and mountains, indiscriminately, though not usually in equal amounts. (*b*) The drift is sometimes so disposed as to make the surface much rougher than it would be otherwise, and sometimes so as to give it less relief. This is illustrated by Figs. 478 and 479. (*c*) The drift is measurably independent of present drainage basins, so far as its constitution is concerned. Thus, materials from one drainage basin are found in the drift of other drainage basins so commonly as to make it clear that present divides did not constitute divides to the ice. (*d*) Various sorts of material in the drift at certain points are so related to their sources as to make it clear that they were carried upwards, sometimes hundreds of feet, from their original sites, a point which is often readily established in the case of large bowlders. Glaciers can do this sort of work, under proper conditions, but water, unaided by ice, cannot. (*e*) A con-

siderable area in southwestern Wisconsin, and the adjacent parts of Illinois, Iowa, and Minnesota, is without drift. The driftless area [1] of these states is neither notably higher nor lower than its surround-

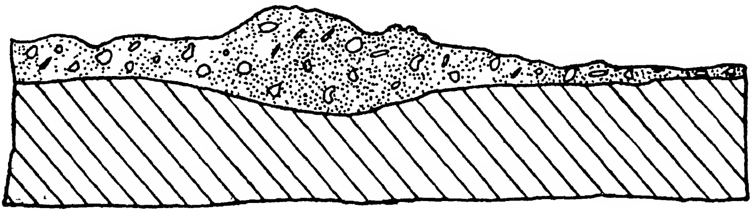


FIG. 478.—Figure to illustrate the disposition of the drift in such manner as to increase the relief of the surface on which it lies.

ings, and the agent which produced the drift must have been such as could avoid this area. Glacial ice seems to be the only agent competent to the result. (*f*) Stratified drift often extends beyond the unstratified, in the direction in which the ice was moving, especially

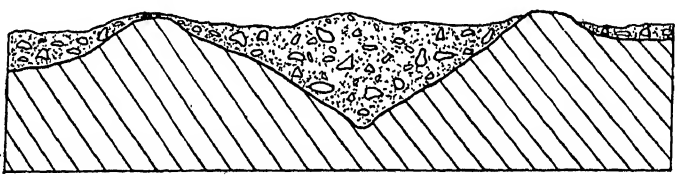


FIG. 479.—Diagram to illustrate (1) the disposition of drift, the drift being thick in the valleys and thin or absent on the hills; (2) the effect of the drift on topography, making it less uneven; and (3) the sharp contact between firm rock below and the drift above.

in valleys and on low land. This peculiarity of distribution is the result of running water.

The first five of these points, *a–e*, make strongly for the conclusion that the drift is a product of glaciers, while the sixth (*f*), is consistent with this conclusion.

(5) **Topography of the drift.**[2]—Among the characteristic features of the topography of the drift are: (*a*) Depressions without outlets, and (*b*) knobs, hills, and ridges, similar in size to the depressions,

[1] Winchell, Ann. Rept. Minn Geol Surv., 1876, pp. 35–38; Irving, Geol. of Wis, Vol. II, pp. 632–633; Chamberlin, Ann Rept. Wis. Geol. Surv., 1878, pp. 21–25, and Chamberlin and Salisbury, Sixth Ann. Rept. U. S. Geol. Surv., 1885, pp. 199–322.

[2] This, as well as other characteristics of the drift, is discussed in 3d Ann. Rept. U. S. Geol. Surv.

associated with them (Figs. 480 and 481). Many of the depressions contain standing water. The surface of some parts of the drift, on

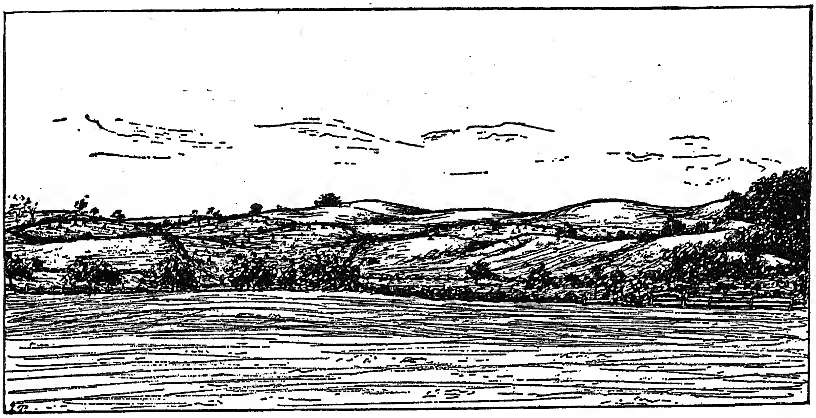


FIG. 480.—A sketch of the drift (terminal moraine) topography near Hackettstown, N. J. (New Jersey. Geol. Surv.)

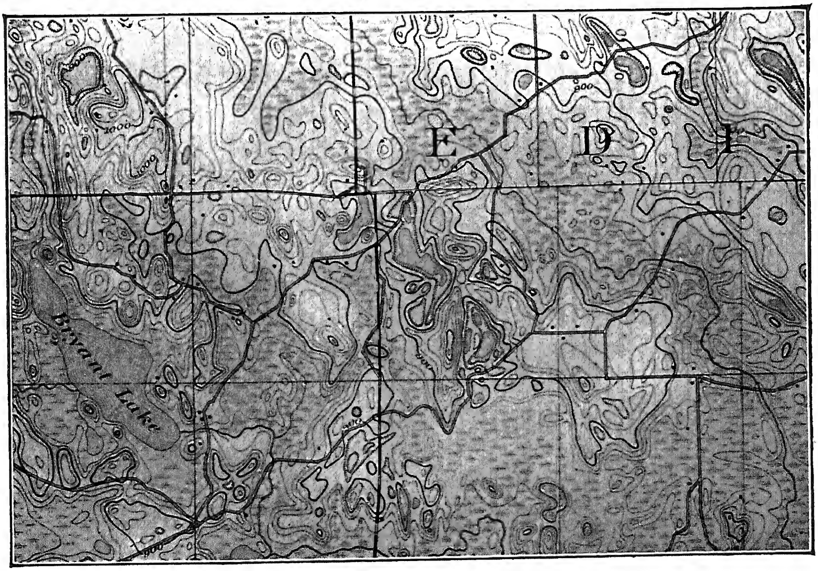


FIG. 481.—The topography of the drift shown in contours for an area near Minneapolis, Minn. Scale approximately a mile to an inch. (U. S. Geol. Surv.)

the other hand, is nearly plane. Neither planeness nor unevenness can be ascribed exclusively to the stratified nor to the unstratified

drift. Either may be rolling, or either may be plane, though the phases of topography assumed by the two sorts of drift are somewhat unlike.

The significance of the topography of the drift at this point lies in the fact that no agent of deposition, except glacial ice, makes deposits of such topography over great areas, in measurable disregard of the topography of the underlying rock. That glaciers develop such topography is shown by the fact that the drift deposited by glaciers in recent times, has a topography similar to that possessed by the drift. It is to be noted, however, that no very recent glacial deposits, comparable in area to the drift, are now accessible. Negatively, it may be added that no other agent of deposition except land ice is believed to be capable of developing such topography as that possessed by much of the drift.

(6) **Thickness of the drift.**—The thickness of the drift ranges from zero to more than 500 feet, and the variations are often great within short distances. One hill may be composed of drift, while the next has no more than an interrupted mantle of drift (Figs. 478 and 479). The drift may be thick on hills and thin in valleys, but more commonly the reverse is the case. These facts are of significance in this connection in that the thickness is often independent of the topography of the underlying surface. No agent besides glaciers so habitually leaves its deposits so unequally distributed, and in such disregard of preëxisting topography.

(7) **Contact of drift and underlying rock.**—The plane of contact between the drift and the underlying rock is generally, though not always, sharply defined, and the surface of the rock is likely to be fresh and firm (Fig. 482). When this relation is contrasted with that between the mantle-rock and the underlying formations where there is no drift (Fig. 489), the conclusion is forced that in the regions of drift the surface was stripped of all loose debris, and ground down to the solid rock below, before the drift was left upon it. This is exactly what glaciers are now doing.

(8) **Striation and planation.**[1]—The rock surface beneath the drift, and especially beneath the unstratified drift, is frequently polished, planed, striated (Fig. 482), and grooved (Fig. 483). These features are widespread throughout the drift-covered area, and they occur

[1] 7th Ann. Rept. U. S. Geol. Surv , pp 155–248 An elaborate discussion of this topic.

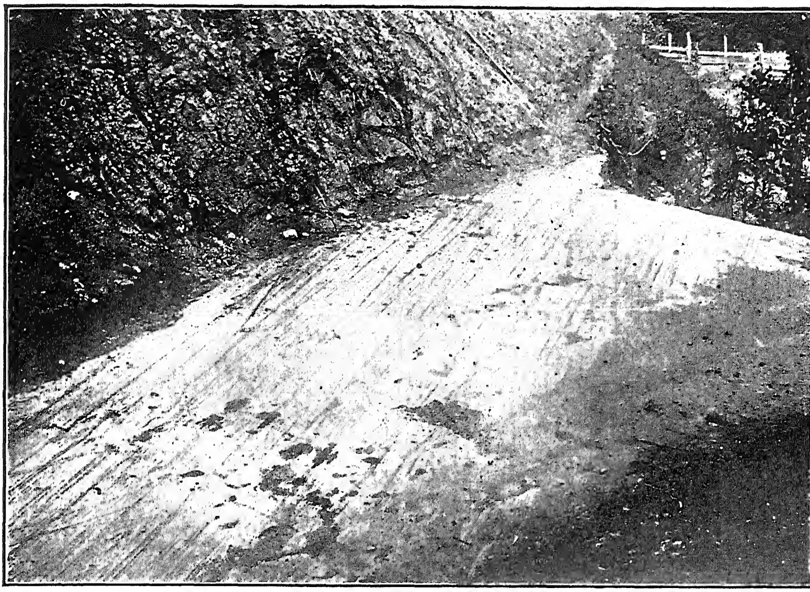


FIG. 482.—Striæ on bed-rock, Kingston, Des Moines County, Ia. (Ia. Geol. Surv.)

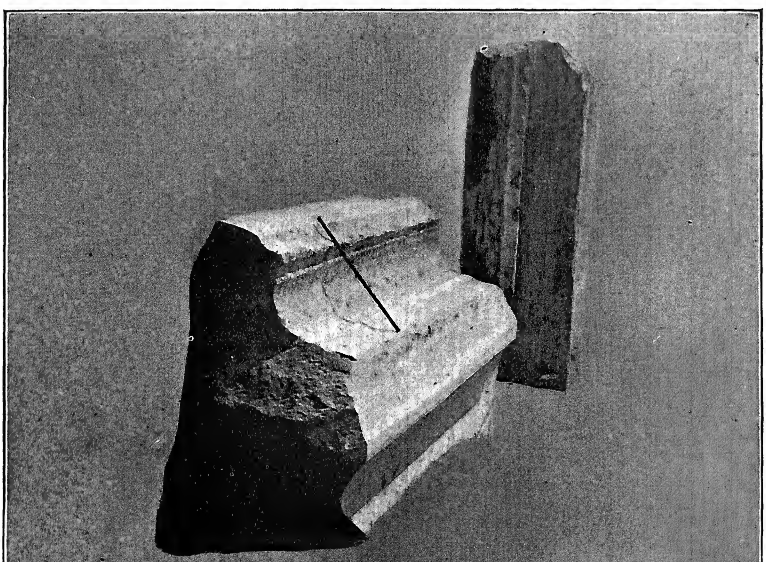


FIG. 483.—Grooves in limestone on Kelley's Island, Lake Erie. The grooves show by their lack of strict parallelism that different parts of the grooving were accomplished at somewhat different times. The foot-rule indicates the scale, and its shadow defines the groove. (U. S. Geol. Surv.)

at all elevations where the drift occurs. The markings on the bed-rock beneath the drift are so like those on the stones of the drift, that community of origin cannot be doubted.

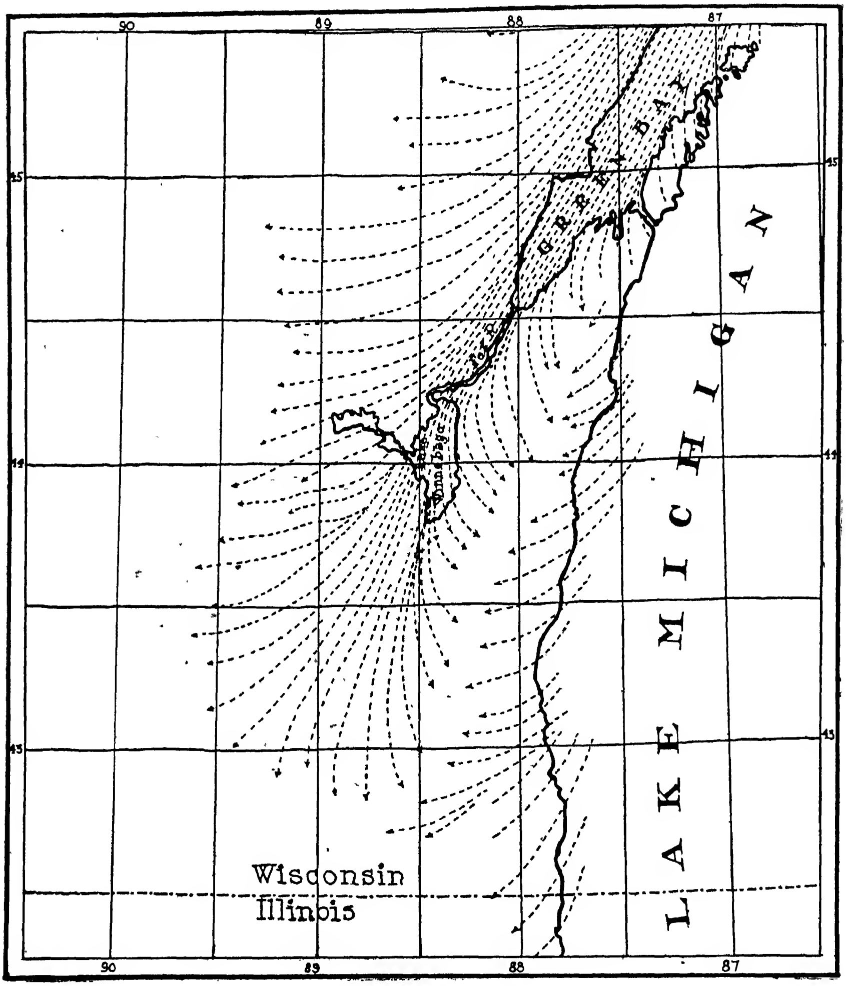


FIG. 484.—The radiation of striæ in the Green Bay glacial lobe, and in the west part of the Lake Michigan lobe, during the last glacial epoch.

The striæ on the bed-rock beneath the drift are generally approximately parallel in any given locality, and tolerably constant in direction over considerable areas. When large areas are studied, the striæ are sometimes found to be far from parallel. In general, their depar-

ture from parallelism is according to a definite system, for they radiate from the centers already named (Fig. 470). Not only this, but there are systematic radiations of striæ within the lobes of ice which characterized the borders of the great ice-sheets at the stages when it was most influenced by the broad depressions of the Great Lake region

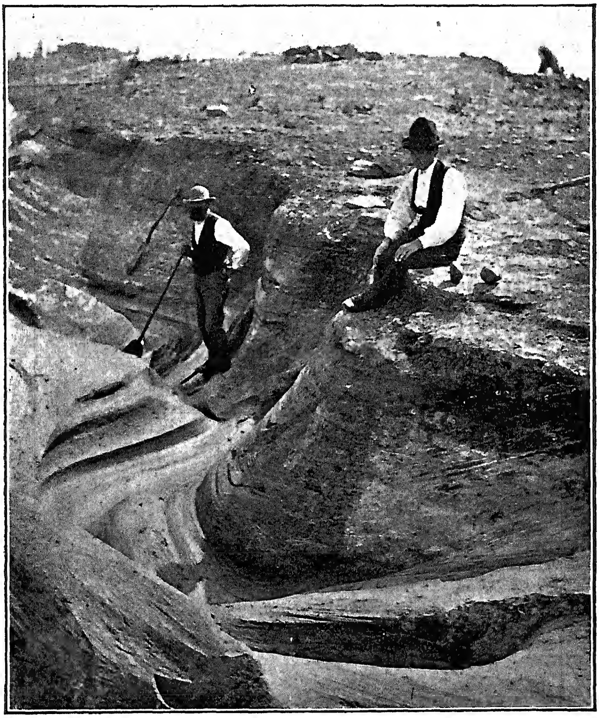


Fig. 485.—Tortuous glacial grooving. The gorge is believed to be due to a subglacial stream, into the channel of which the ice settled down, moulding itself to the gorge and grooving it. Kelley's Island, Lake Erie. (U. S. Geol. Surv.)

(Fig. 484). The direction of striæ corresponds with the direction in which the drift was transported.

Sometimes striæ and grooves follow narrow and tortuous gorges (Fig. 485). Striæ are not confined to horizontal or even to gently inclined surfaces. They occur on steep slopes (Fig. 486), not infrequently on the vertical faces of cliffs, and, occasionally, even on the under sides of overhanging rock masses.

Besides the striæ, grooves, etc., on the bed rock, there are often other details of surface which are equally characteristic. Minute

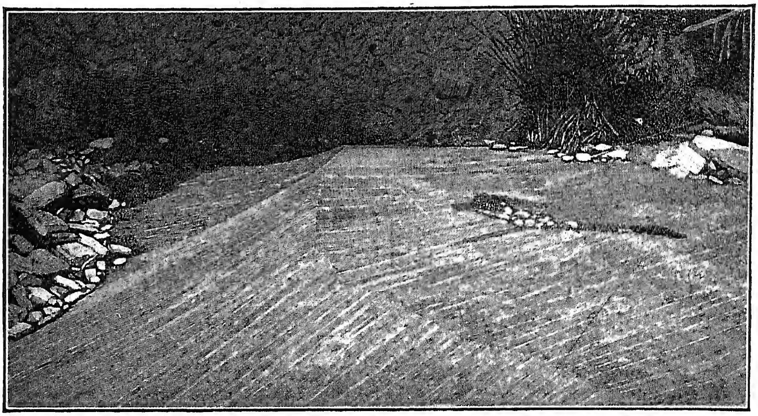


FIG. 486.—Striæ on two contiguous surfaces which meet each other at a large angle. Southeast shore of Kelley's Island, Lake Erie. (U. S. Geol. Surv.)

protuberances of surface often show more wear on one side than on the other (Fig. 487 and 488). Minute depressions (Fig. 488), show

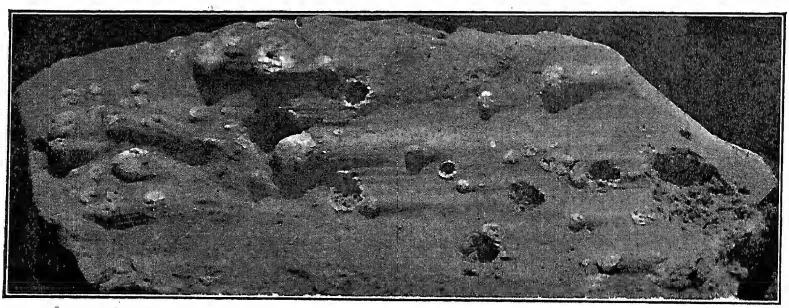


FIG. 487.—Small protuberances of rock showing the effect of ice wear. Glacial knobs and trails. The projections consist of chert in limestone. Near Darlington, Ind.

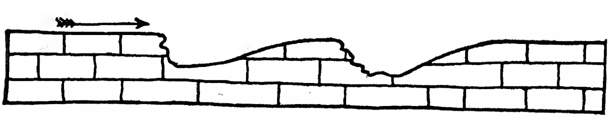


FIG. 488.—Diagram to show the effect of ice wear on slight depressions in the surface of rock.

analogous features. The significant point in these features is that the same sides of the protuberances, and the same sides of the depres-

sions in any given locality, show the greater wear, and indicate the direction of ice-movement. Other markings, such as chatter marks, distinctive of ice work, are also found on the bed-rock, though less commonly than striæ, grooves, etc.

(9) **The shapes of rock hills.**—The rock knolls which were left bare when the ice retreated, often show peculiarities of form and surface which are distinctive. Like the minute protuberances of surface just

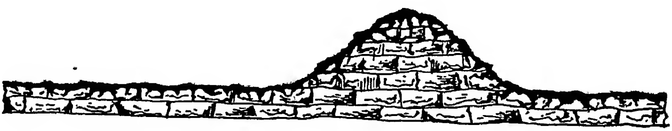


FIG. 489.—Diagrammatic representation of a hill unworn by the ice. The diagram also shows the irregular contact between the surface earths and the rock below.

referred to; the rock hills of many localities over which the ice passed were systematically worn more on the side from which the ice approached (the stoss-side), than on the other (Fig. 490). Bosses of rock

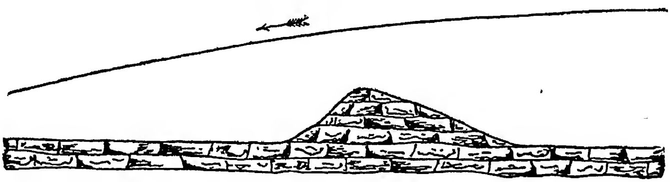


FIG. 490.—Diagram to show the effect of glacial wear on such a hill as that shown in Fig. 488.

which do not show pronouncedly unequal wear often show distinctive smoothing (Fig. 491). Projecting glaciated knolls of rock, whether large or small, which show the characters seen in Fig. 492, are known as *roches moutonnées*. A succession of roches moutonnées generally give fairly accurate information as to the direction of ice movement, even though striæ be not preserved.

Summary.—The characteristics of the drift, as set forth in the preceding paragraphs, leave little room for random speculation concerning its origin. From its variable thickness we know that the force or forces which produced it must have been such as could leave the drift now in thick bodies and now in thin, over either limited or extensive areas. From its distribution we know that the force or forces which produced it were largely independent both of underlying

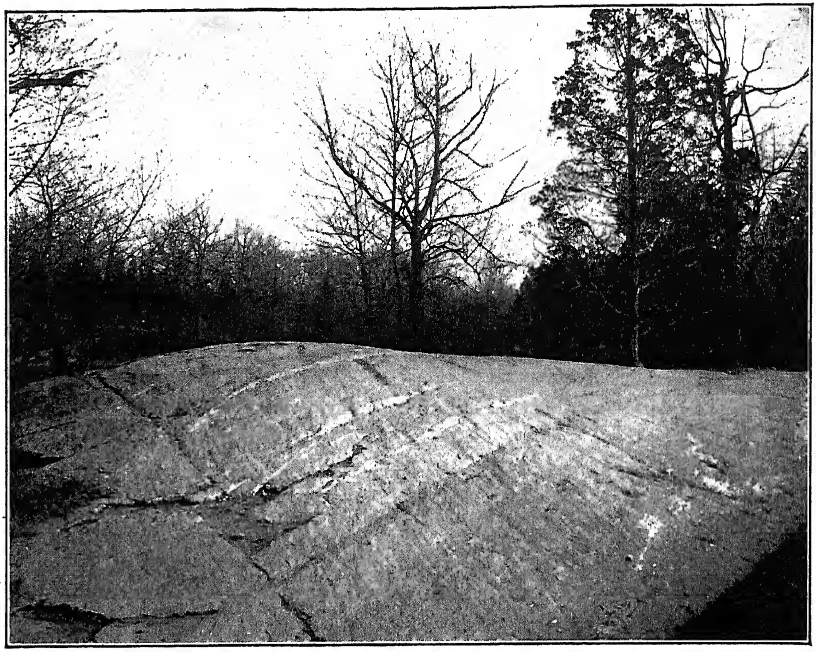


FIG. 491.—A polished surface of rock in Bronx Park, N. Y. (Willis, U. S. Geol. Surv.)

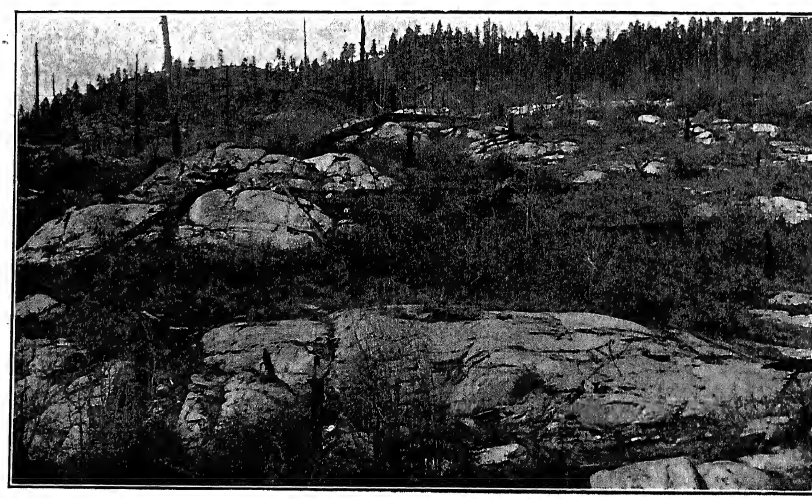


FIG. 492.—Roches moutonnées.

rock formations and of topography. From its physical make up we know that the agency or agencies which produced it must have been able to carry and deposit, at one place and at one time, materials as fine as the finest silt or mud, and bowlders many tons in weight, while they were competent, under other circumstances, to make deposits of much less extreme diversity. From its lithological make up, and from the nature of the finer parts of the drift, we know that the drift forces worked on different sorts of rock, deriving materials from many; that they ground some of the materials into a fine earthy powder or "rock flour," commonly called clay; that they as a rule derived the larger part of the drift of any locality from formations near at hand; and that the materials, even large bowlders, were sometimes carried up to altitudes considerably above their source. From the structure of the drift it is concluded that the drift force or forces must have been capable of producing deposits which were sometimes stratified and sometimes unstratified, and that the deposition of these two phases of drift was sometimes contemporaneous and sometimes successive, the number of alternations sometimes being considerable. From the striæ on the stones of the drift it is known that the production of the drift must have involved the action of forces which, under some conditions, were capable of planing and beveling and striating many stones, especially the softer ones of the unstratified drift, while rounding and leaving unstriated most of those of the stratified; but that the agency or agencies concerned must have been such that under certain circumstances their activities failed, on the one hand, to leave more than a very small percentage of the stones of the unstratified drift beveled and striated, while, on the other hand, they sometimes permitted the stratification of gravels containing many subangular, plane-faced, and striated stones, varying in size from pebbles to bowlders. From the striæ on the bed-rock beneath the drift and the unweathered character of the surface of the rock, it is clear that severe wear was inflicted on the surfaces over which the drift was spread, while the positions in which the striæ were developed show that the agency which inflicted the wear was able to adapt itself to all sorts of surfaces. The general parallelism of striæ in a limited area, and the systematic departure from parallelism over great areas, are also significant of the manner in which they were produced. From the topography of the drift it is known that the forces which produced it must have been such as

were able to develop plane surfaces at some points, surfaces marked by more or less symmetrical drift-hills, which are measurably independent of rock-topography at others, and short, choppy hills, associated with undrained depressions, in still others.

The true theory of the drift must explain all these facts and relations. Any hypothesis which fails to explain them all must be incom-

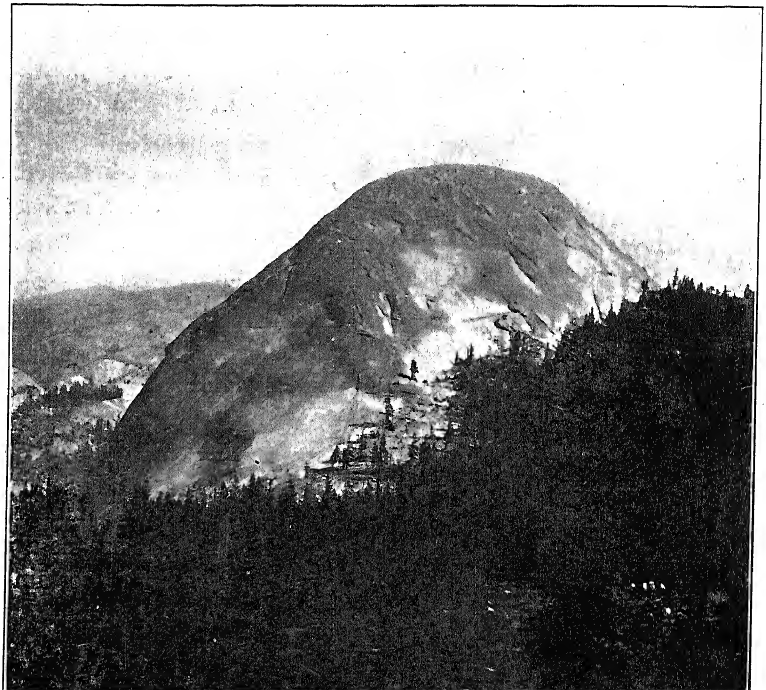


Fig. 493.—Glaciated dome, Tuolumne Valley, Cal.

plete at the least, and any hypothesis with which these facts and relations are inconsistent, must be false.

Geologists are now very generally agreed that glacier ice, supplemented by those other agencies which glacier ice calls into being, is the only agent which could have produced the drift. But it is not to be forgotten that this does not preclude the belief that at various times and places, in the course of the ice period, icebergs may have been formed, or that locally and temporarily they played an important role. It does not preclude the idea that, contemporaneously with

the production of the great body of the drift by glacier ice, the sea may have been at work on some parts of the present land area, modifying the deposits made by ice and ice drainage. Indeed, there is abundant evidence that such was the fact, for some regions, now covered by drift, stood lower than now, relative to sea level, when the drift was deposited, or since. The glacial theory does not deny that rivers produced by the melting of the ice were an important factor in transporting and depositing drift, both within and without the ice-covered territory. It does not deny that lakes formed in one way and another through the influence of ice, were locally important in determining the character and disposition of the drift. Not only does the glacier theory deny none of these things, but it distinctly affirms that rivers, lakes, the sea, icebergs, and pan-ice must have coöperated with glacier ice in the production of the drift, each in its appropriate way and measure, and that after the disappearance of the ice and the ice-water, the wind had its appropriate effect on the drift before it became clothed with vegetation.

The Development and the Thickness of the Ice-sheets.

The development of glaciers from snow-fields has been discussed in Volume I, but a few words with reference especially to the development and thickness of the ice-sheets of our continent, are here added.

If the expansion of the ice-sheets was due principally to movement from a center or centers, the ice at these centers must have been prodigiously thick, for in the course of its progress it encountered and passed over hills, and even mountains, of considerable height. In the vicinity of elevations which it covered, its thickness must have been at least as great as the height of these elevations above their bases. If such elevations were remote from the center of movement, the ice must have been still thicker at those centers, to afford the necessary "head."

If the centers of the North American ice-sheets remained the centers of movement throughout the glacial period, and if the degree of surface slope necessary for movement were known, the maximum thickness of the ice could be calculated. It is probable, however, both that the centers of the ice-sheet did not remain the effective centers of movement, and that the surface slope necessary for movement was variable.

If the fall of snow toward the margin of the ice-sheet greatly exceeded that at its center, as it probably did, an infra-marginal belt, rather than the geographic center of the field, may have controlled the marginal movement of the ice. With excess of infra-marginal accumulation, the surface slope of the ice would be relatively great from the zone of maximum accumulation to the edge of the ice, but might be very slight, or even nil, within it (Fig. 494). Under these circumstances, the extension of the ice being due largely to dispersal from the infra-marginal zone, the maximum thickness of the ice-sheets might be notably less than if the geographic center remained the effective dynamic center.

In an ice-sheet like that which was responsible for the drift of North America, it is probable that all influencing and limiting conditions which may exist in any ice-sheet were found. The varying pressures

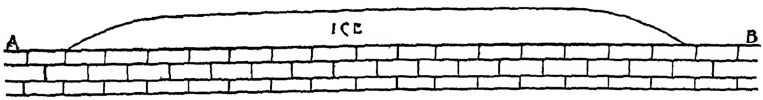


FIG. 494.—Diagram to illustrate the surface configuration of a great ice-sheet, according to the conception here presented. The central part is relatively flat and the margins have steep slopes.

and temperatures to which its various parts were subject tended to produce various degrees of mobility in its mass, and varying degrees of mobility demanded varying degrees of surface slope in order to bring about movement. Could the surface slope necessary for movement be determined for any given region, and for any given time during the glacial period, it does not follow that the same slope was necessary for the whole ice-sheet, or even that it was necessary for any particular region, at all stages of its glacial history. Both observation on existing glaciers and ice-sheets, and considerations of a physical nature, make it certain, first, that the angle of slope must have decreased with increasing distance from the margin of the ice (that is, with increasing thickness of the ice) until, at the center of the field, it approached zero; and second, that at the edge of the ice-sheet, where the ice was thinnest, the surface slope was greatest.

No sufficient data are at hand for determining with accuracy the average slope of such an ice-sheet as that which covered our continent, but something is known of its slope at certain points. Near

Baraboo, Wis.,[1] the edge of the ice at the time of its maximum extension in that region lay along the side of a bold ridge, the axis of which was nearly parallel to the direction of ice movement. The position of the upper edge of the ice against the slope of the ridge is sharply defined. For the last one and three-fourths miles, its average slope was about 320 feet per mile. This, it is to be noted, was at the extreme edge of the ice, where the slope was at a maximum. In Montana, the slope of the upper surface of the ice for the 25 miles back from its edge has been estimated at 50 feet per mile.[2] Calculations based on data from New Jersey and adjacent parts of New York, indicate for this region a slope of about 30 feet per mile [3] for the upper surface of the ice when it was there thickest. It is to be noted that the data for this calculation were drawn from localities which, while relatively near the edge of the ice-sheet, were still some miles within it. At first thought, a surface slope of 30 feet per mile does not seem excessive, for the surface of such a slope would seem to the eye to be nearly plane; yet even so moderate a slope may lead to very extraordinary conclusions.

The southern limit of drift in Illinois is not less than 1500 or 1600 miles from the center of movement. An average slope of 30 feet per mile for 1500 miles would give the ice a thickness of 45,000 feet at a point 1500 miles from its margin, if the slope of the surface on which the ice rested be disregarded, and this slope was so little as to be of no great consequence in this connection. This thickness, more than eight miles, seems incredible. Even an average slope of 10 feet per mile would give a thickness of nearly three miles at the center of the ice-sheet. If by reason of relatively great infra-marginal accumulation, the only part of the ice-cap which had any considerable slope was its marginal part, the surface of the central portion being nearly flat, so great a maximum thickness would not be demanded.

Nansen [4] found that the surface of the ice-sheet of Greenland rose abruptly at either margin, and less and less rapidly as its summit was approached. He crossed the ice where it was about 250 miles wide. On the east side he found a slope of about 220 feet per mile, and on

[1] Jour. of Geol , Vol III, p 655.
[2] Calhoun, Jour. of Geol., Vol. IX, p 718.
[3] Smock, Am. Jour. Sci , Vol. XXV, 3d Series, p. 339.
[4] Nansen, The First Crossing of Greenland, Vol. II, p. 465.

the west, 142 feet per mile, for the first 1000 meters of ascent. For the second 1000 meters of rise, the slopes were 93 and 63 feet per mile, respectively; while for that part of the snow-field more than 2000 meters high, and more than 50 miles from the east edge and more than 76 miles from the west edge, the slope ranged from 26 to 37 feet per mile. From these data it is fair to conclude that if the ice-sheet were much larger, like that of our continent during the glacial period, the gradient would be still less toward its center.

Stages in the history of an ice-sheet.—The history of an ice-sheet which no longer exists involves at least two distinct stages. These are (1) the period of growth, and (2) the period of decadence. If the latter did not begin as soon as the former was completed, an intervening stage, representing the period of maximum ice extension, must be recognized. In the case of the ice-sheets of the glacial period, each of these stages was probably more or less complex. The general period of growth of each ice-sheet is believed to have been marked by temporary, but by more or less extensive, intervals of decadence, while during the general period of decadence, it is certain that the ice was subject to temporary, but to more or less extensive, intervals of recrudescence.

In the study of the work accomplished by an ice-sheet, it is of importance to distinguish between these main stages, and, in the last analysis, to take account of the oscillations of the edge of the ice in each.

The Work of an Ice-sheet.

Glacial erosion and glacial deposition have been briefly discussed in Volume I (p. 281–305). It need only be added here that the surface over which the ice-sheets moved is believed to have had a topography which had been shaped, so far as details are concerned, by rain and river erosion, and was covered by a layer of mantle-rock which originated in the decay of the formations beneath. The ice removed this mantle of decomposed material, and cut deeply into the undecayed rock beneath. The best rough measure of the ice erosion is the great body of drift, much of which is composed of rock debris, which lay beneath the decayed horizon at the surface. In effecting this erosion, the ice modified the preëxisting topography to some extent, for weaker terranes were eroded more than resistant ones, and the topog-

raphy favored more forcible abrasion at some points than at others, while the ice itself was more effective at some times and places than at others. One of the results was the development of rock-basins by the ice-sheets. On the whole, the topographic effect of glacial erosion was probably to soften the surface contours, without noticeably diminishing the relief. The erosive effect of an ice-sheet of large size is probably greatest toward its edge, but far enough back for the ice to be thick. The position of the area of greatest erosion probably shifted with the decline of the ice-sheet.

The second great phase of the work of the ice was the deposition of the drift. Some of it was deposited while the ice-sheets were growing, some of it after they had attained their growth and before decay had begun, and some of it while they were declining. Some of it was deposited beneath the body of the ice, and some of it at its edge. In some places, water played an important role in modifying the drift left by the ice, while in others its influence was nil. The deposition of the drift altered the topography notably, especially where the drift was thick and the relief of the underlying rock slight. It is to the inequalities in the thickness of the drift that many of the peculiar depressions and elevations of the surface of the drift are chiefly due. Erosion and the deposition of the eroded material are then the two great results of an ice invasion, so far as the solid part of the earth is concerned. The effects on life will be considered later.

The drift formations fall chiefly into three categories, namely (1) those made directly by the ice (unstratified), (2) those made by ice and water conjointly (stratified, but stratification often irregular), and (3) those made by water emanating from the ice (stratified, often with cross-bedding). To these deposits should perhaps be added, (4) deposits made by floating ice derived from glaciers, and (5) the eolian deposits to which the glacial deposits gave origin.

Formations made by the Ice-sheets.[1]

The *ground moraines*, the *terminal moraines*, and the *lateral moraines* are the principal types of drift deposited by the ice directly. Of these, the ground moraines are by far the most extensive, while in connec-

[1] Jour. of Geol., Vol. II, pp. 517–538, and Inst. Geol. Congr. Compt. Rend., 5th Session, 1893; also McGee, idem.

tion with the ice-sheets, lateral moraines (Vol. I, p. 302) have little development.

The ground moraine (Vol. I, p. 301) is the most familiar and wide-spread phase of drift, and its features are those usually given as characteristic of drift in general. The ground moraine (or *till*) is nearly co-extensive with the ice-sheets themselves, though it failed to be deposited in some places, and it has been removed, or buried by stream deposits, in others. The ground moraines of the North American ice-sheets are thickest far from the centers of the ice-fields, in a broad infra-marginal belt extending from central New York through central and northern Ohio, Indiana, Illinois, Iowa, Minnesota, and Dakota, and northward to an unknown limit in Canada.[1] Towards the centers of the ice-fields, and often near their outer borders, the drift is thin, because in the former place it was never left, and in the latter often because it has been removed by erosion.

The topography of the ground moraine varies within wide limits. It may be nearly plane, but is more commonly gently undulatory, the undulations involving gentle sags and swells. The former are often the sites of marshes, ponds, and lakes (right-hand part of Fig. 498). The sags and swells frequently show a tendency to elongation in the direction of ice movement. The hills of ground moraine sometimes take on rather definite elongate shapes, with their longer axes in the direction of ice movement and two to ten times the shorter. Such hills of till are *drumlins* (Figs. 495 and 496). They are the most distinctly defined aggregations of ground moraine. Many hills and swells of the ground moraine, however, are not drumlins. Drumlins find their most pronounced development in the United States in eastern Wisconsin, where their number has been estimated at 10,000 (Buell), and in central and western New York,[2] though they are not confined to these localities. The drumlins of New York (Fig. 496) are, in general, much longer than those of Wisconsin.

The origin of drumlins has been much discussed, but there is, as yet, no generally accepted conclusion, and the subject is still under active inquiry. Opinion is chiefly divided between the views,

[1] For descriptions of the ground moraine in various regions, see State Reports.

[2] For the topography of the drumlins, see the following topographic sheets U. S. Geol. Surv.: Wisconsin: Sun Prairie, Watertown, and Waterloo; New York: Oswego, Palmyra, Clyde, Brockport, and Weedsport; Massachusetts: Boston.

(1) that they were accumulated beneath the ice under special conditions, and (2) that they were developed by the erosion of earlier aggregations of drift, much as roches moutonnées are developed. Under the first of these general views, it has been suggested (1) that the bars of rivers give the clue to the origin; (2) that protuberances of rock gave occasion for the lodgment; (3) that the balance between load and strength of movement furnishes the key to their explanation,

FIG. 495.—Drumlins shown in contour near Sun Prairie, Wis. (U. S Geol. Surv.)

a slight but not excessive overload being the condition necessary for their development; and (4) that they may be, in some way, connected with longitudinal crevasses.[1]

[1] Papers on Drumlins.—Hall, Geol. Fourth District of New York, 1873, pp. 414–5; Lapham, Smiths. Contr. for 1855; Shaler, Proc. Bos. Soc. Nat. Hist. 1870, pp. 196–204; C H. Hitchcock, ibid, Vol. XIX (1876), pp. 63–67; Matthew, Geol. Surv. of Can., Rept. 1877–79, pp. 12–14, EE; Upham, Proc. Bos. Soc. Nat. Hist. 1879, pp 220–234, ibid., Vol. XXIV (1889), pp. 228–242, Geol. of N. H., Vol. III (1878), Am. Geol. Vol X (Dec. 1892), pp. 339–360, and Bull. Geol. Soc. Am. Vol. III (1892), p. 142; Stone, Proc. Bos. Soc. Nat. Hist., Vol. XX (1880), p. 434,; Johnson, Trans. N. Y. Acad. Sci, Vol. I (1882), pp. 78–89, and N. Y. Acad. Sci, Vol. II, pp. 249–266; Chamberlin, Geol. of Wis., Vol. I (1883), p. 283, Proc. Am. Assoc. Adv. Sci. 1886, p. 195, Third Ann. Rept. U. S. Geol Surv., 1883, p. 306, and Jour. of Geol., Vol. I, p. 255–267; Dana, Am. Jour. Sci., Vol. XXII (1883), pp. 357–361; Davis, ibid., Vol. XXVIII (1884), pp. 407–416; Chalmers, Geol. of Can. Rept. 1881–9, Vol. IV, p. 23; Salisbury, Geol. Surv. of New Jersey, Rept. 1891, p. 74, and Glacial Geology of

A terminal moraine (Vol. I, pp. 299–301) is made where the edge of the ice remains nearly stationary in position for a considerable period of time. In constitution it may be very like the adjacent ground

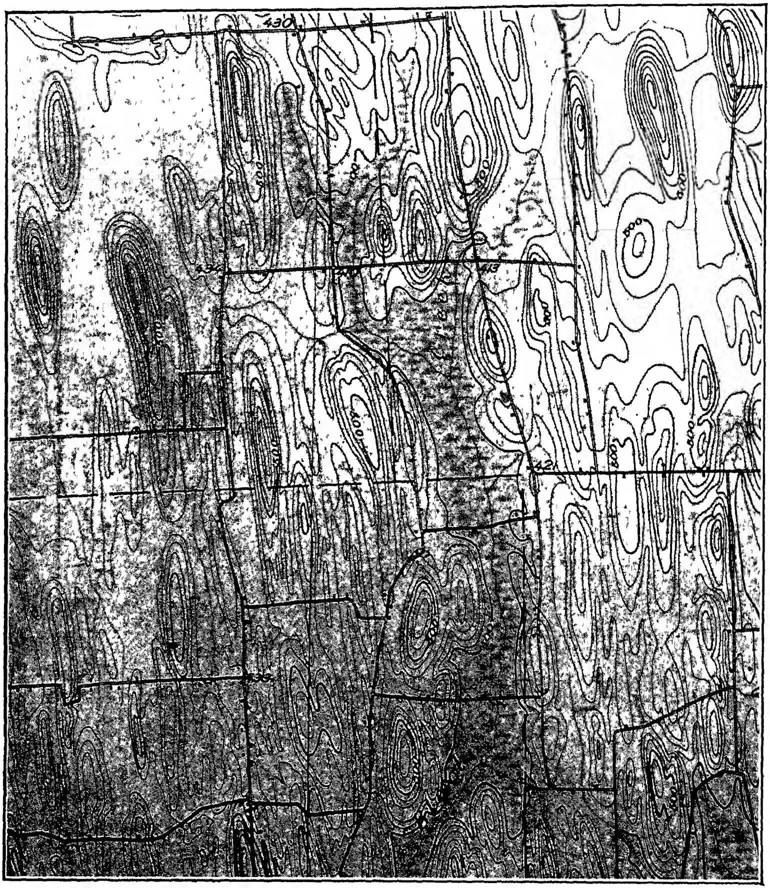


FIG. 496.—Drumlins shown in contour near Clyde, N. Y. (U. S. Geol. Surv.)

moraine, though there is often a larger proportion of stratified drift associated with it. In topography it is somewhat distinctive. It

New Jersey, 1902; Lincoln, Am. Jour Sci, Vol. XLIV (1892), pp. 293–6; Tyrrell, Bull. Geol. Soc. Am., Vol. I (1890), p 402; Barton, Am. Geol., Vol XIII (1894), p. 224; Frank Leverett, Monogrs. XXXVIII and XLI, U. S. Geol. Surv., and Russell, Amer. Geol., Vol. XXXV (1905), p 177.

sometimes constitutes a more or less well-defined ridge, though this is not its most distinctive feature, since its width is generally great, relative to its height. A moraine 50 or even 100 feet high and a mile wide is not a conspicuous topographic feature, except in a region of unusual flatness. In such situations terminal moraines sometimes constitute important drainage divides.

The most distinctive feature of a well-developed terminal moraine

FIG. 497.—Terminal moraine topography near Oconomowoc, Wis. (Fenneman.)

does not lie in its importance as a topographic feature, but in the details of its own topography. Its surface is often characterized by hillocks and hollows, or by interrupted ridges and troughs, following one another in rapid succession, and without apparent order in their arrangement (Figs. 497 and 498). The hollows and troughs are often without outlets, and are frequently marked by marshes, ponds, and lakes wherever the material constituting their bottoms is sufficiently impervious to retain the water falling and draining into them. The shape and abundance of round and roundish hills, and of short and more or less serpentine ridges, often closely huddled together, have locally given rise to such descriptive names as the "knobs," "short hills," etc.

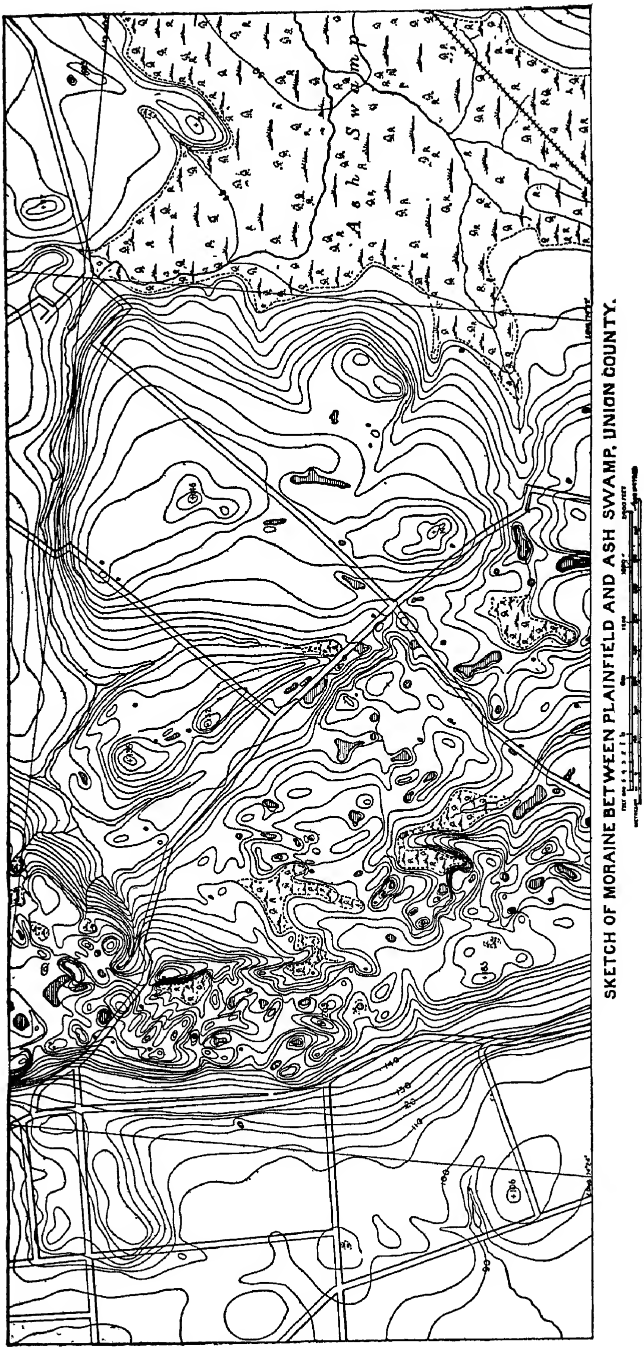


FIG. 498.—A sketch of drift topography near Plainfield, N. J. The central belt of rough and irregular topography is the terminal moraine. The area at the right, about half the area shown in the figure, is ground moraine. The area at the extreme left of the map is the outwash plain. It will be noticed that the interval of the contours is but 5 feet. (N. J. Geol. Surv.)

But it is the association of the "knobs" or "short hills" with the "kettles," and not either feature alone, which is especially characteristic of terminal moraine topography.

The "knobs" vary in size, from low mounds but a few feet across, to considerable hills half a mile or more in diameter, and a hundred feet or more in height. If they attain such heights while their bases are small, their slopes are steep. Not rarely they are about as steep as the loose material of which they are composed will lie.

The "kettles" are the counterparts of the elevations. They may be a few feet, or many rods, or even furlongs in diameter. They may be so shallow that the sagging at the center is scarcely observable, or they may be scores of feet in depth. If steep-sided depressions are closely associated with abrupt hillocks, the topography may be notably rough, and the total relief within a few rods may be nearly equal to the total height of the moraine above its surroundings. The topography of the terminal moraine is often strongly developed, even where the moraine as a whole does not appear as a distinct ridge.[1]

The surface of the terminal moraine, where well developed, is generally rougher than that of the ground moraine, but more because the sags and swells are of smaller area and steeper slopes than because the relief is notably more. It is not to be understood, however, that this peculiar topography always affects terminal moraines, or that it is strictly confined to them. The elevations and depressions of the moraine may grade from strength to weakness, and locally may even disappear, while features closely simulating those characteristic of terminal moraines are sometimes found in other parts of the drift.

Development of terminal moraine topography. — The first condition for the development of a terminal moraine is that the edge of the ice remain approximately stationary in position for a time sufficiently long for the submarginal accumulation to become sensibly thicker than the drift within or without. If the margin of the ice remained constant in position over a region of uniform topography during the formation of a terminal moraine, and if the ice bore equal amounts of material at all points along its margin, the terminal moraine would be developed with some regularity. It would be about as high

[1] The terminal moraines of various regions are described in various state reports and in various reports of the U. S. Geol. Surv., especially the 3d Ann. Rept., and in Monographs XXXVIII and XLI.

and about as wide at one point as at another. If the margin remained constant in position, but bore unequal amounts of material at different points, the moraine would be unequally developed. Where there was much material it would be higher and probably wider than where there was but little. Irregularity of height and width would thus be introduced by reason of the unequal amounts of material at different parts of the ice edge.

If, instead of remaining stationary, the margin of the ice moved alternately backward and forward within narrow limits, the effect would be to spread the moraine by widening the zone of submarginal accumulation. If, during the oscillation of the margin, it remained stationary either during or after its minor recessions or advances, or both, subordinate ridges would be developed, marking the positions of the several halts. If the edge of the ice remained parallel to itself as it advanced and receded, these subordinate ridges would be parallel, and each a miniature terminal moraine. But if while the edge of the ice was carrying unequal amounts of material, its edge oscillated unevenly, with halts, that is, if recessions and advances were unequal at different points, the several subordinate ridges formed at the various positions of halt would not be parallel, and would not be equal in height or width, and no one of the ridges would be uniform in size throughout its course. Adjacent ridges might touch each other at some points, and be separate from each other by considerable intervals at others. The result would be a series of interlocking moraine ridges of variable heights and widths, constituting a "tangle" of moraine hills and ridges, with depressions of various shapes and sizes. In this way it is believed many of the characteristic hills and hollows of terminal moraines arose. If marginal masses of ice were detached from the main body during its temporary recessions, they might subsequently be buried by deposits of drift. Later, when these buried ice-blocks melted, a kettle-like depression, marking the site of the buried ice block, would result. Thus would be added another element of complexity in the topography of the terminal moraine. Such surface débris as there may have been on the ice while the edge was stationary was continually being dropped (dumped) at the edge of the ice. If the edge of the ice oscillated, this drift would have been scattered over a zone as wide as the zone of oscillation. Wherever and whenever the edge remained perfectly stationary, there was a

tendency for the surface débris to be dumped at the edge along a definite line. Locally, where the débris dumped was mainly bowlders, a wall-like ridge (*Geschiebewall*) was developed in such a position. Such bowlder-walls have received little emphasis in America, although they are known to exist at various points.

The ridges and mounds of débris brought to the surface of the ice near its edge by the upturning layers (Fig. 271, Vol. I) may be a further, though very subordinate, element in the development of terminal moraine topography.[1]

Where an ice-sheet or a glacier halted in its retreat, its edge or end remaining in a constant or nearly constant position for a sufficiently long period, a terminal moraine was developed. Such a terminal moraine is often called a *recessional moraine*. Some caution is needful in the use of this term lest it be the occasion of misinterpretation. While formed in a general time of retreat, some of these later moraines represent appreciable advances, while others apparently represent halts merely, and some may possibly signify only an unusually slow rate of recession, by reason of which a deeper accumulation of drift took place. The not uncommon impression that a terminal moraine is one which, by its very name, marks the *terminus of the drift*, is fundamentally erroneous and very objectionable, since the word terminal merely relates to the *terminus of the ice* which formed the moraine, and is contrasted with medial and lateral. It has no relation to the stage of advancement or of retreat of the terminus of the ice. No one moraine marks the border of the drift throughout its entire extent, and confusion arises from the attempt to substitute *the border of the drift*, for *the edge of the ice*, in the significance of the word terminal.[2]

[1] Jour. of Geol., Vol. IV, 1896, pp. 793–800.

[2] References on terminal moraines: Whittlesey, Smiths. Contr., 1866; Dawson, G. M., Q. J. G S., Nov. 1875, p. 614; Chamberlin, Trans. Wis Acad. Sci., Vol. IV, (1876–7), pp. 201–234, Proc. Int. Cong. Geologists, Paris, 1878, Third Ann. Rept. U. S. Geol. Surv., 1881–2, pp. 291–402, and Amer. Jour. Sci., Vol. XXIV (1882), pp. 93–97; Irving, Wis. Geol. Surv., Vol. II (1877), pp. 615–634; Cook and Smock, New Jersey Geol. Surv., 1876–7, and 1877–8; Hitchcock, N. H. Geol. Surv , Vol. III (1878), pp. 218, 230–236, 246, 301–5, 337; Upham, Amer. Jour. Sci., 1879, pp. 81–92, 197–209, Minn. Geol. Surv., Vol. I (1884), Can. Geol. Surv., Vol. IV, 1889, pp. 44–5 E, Proc. Amer. Assoc. Adv. Sci., Vol. XXXII (1883), pp. 213, 232, and Rept. Minn. Geol. Surv., 1880, pp. 281–356; Sweet, Wis. Geol. Surv., Vol. III (1880), p. 384; White, I. C., Penn. Geol. Surv., 1880, p. 26; Winchell, N. H., Ohio Geol. Surv., Vol. II,

Fluvio-Glacial Deposits.

The phenomena of existing glaciers afford warrant for the view that the waters arising from the melting of the ice-sheets organized themselves, to a greater or less extent, into streams [1] before they left the ice (Vol. I, p. 280). This was doubtless true to a larger extent near the edge of the ice than farther back. Ultimately, the subglacial and englacial waters escaped from the ice. When this took place, the conditions of flow were more or less rapidly changed, for instead of being confined to tunnels, under hydrostatic pressure, as heretofore, the streams now followed the laws governing normal river-flow. When the streams entered standing water, as was sometimes the case, the standing water modified the results which the running water would otherwise have produced (Vol. I, pp. 305–307). The water issuing from the ice thus made deposits in several classes of situations.

(1) **At the edge of the ice.**—Where subglacial streams flowed under "head," the pressure was relieved when they escaped from the ice, and diminution of velocity and deposition of load were the common results. Since these changes took place at the edge of the ice, aqueous deposits were sometimes made in this position, in immediate contact with the ice itself. The edge of the ice was probably more or less ragged, and the deposits made by the issuing waters were sometimes left in the reëntrant angles and marginal crevasses. When the ice against which the river-deposited débris was banked, melted, the gravel, sand, etc., assumed the form of mounds, hillocks, and short ridges. Such knobs, hills, and ridges are *kames* (Fig. 499). Kames may be developed in other ways, but they are primarily phenomena of the margin of the ice, developed by running water (the active agent) in association with ice (the passive partner).

In position, kames have some relation to terminal moraines, and there is perhaps no situation in which they are so numerous as in asso-

Minn. Geol. Surv., Vol. I (1884); Lewis and Wright, Second Geol. Surv. Pennsylvania, Rept. Z, 1882; Tyrrell, Amer. Geol., Vol. VIII, pp. 19–28 (1891); Bell, Bull. G. S. A., Vol. I., pp. 303, 306; Salisbury, Glacial Geology of New Jersey, pp. 93–100 and 231–260; Leverett, Monogrs. XXXVIII and XLI., U. S. Geol. Surv.; Todd, Bulls. 144 and 158, U. S. Geol. Surv., 1896 and 1899, and Am. Jour. Sci , 4th ser., Vol. VI, pp. 489–477, 1898. See also State Geological Reports of States affected by the ice-sheets.

[1] The general topic of ice drainage is discussed in Glacial Geology of New Jersey, p. 113 et seq , and Jour. of Geol., Vol. IV, p. 950 et seq.

ciation with such moraines. Many of the conspicuous peaks, knobs, and hills of the latter are, individually, kames. Belts of kames having the general position, relations, and significance of terminal moraines are called *kame moraines.*[1] Kames occasionally attain a height of 100 feet or more, but heights of 20 to 40 feet are much more common.

The stratification of the sand and gravel of which the kames are

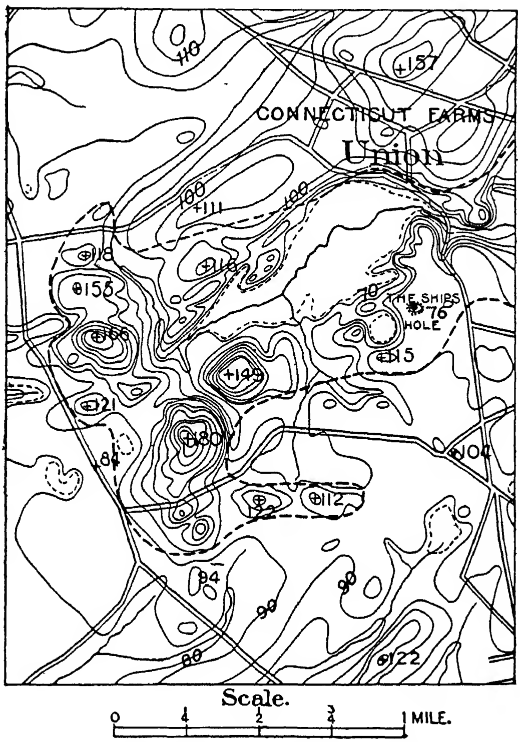


Fig. 499.—A group of kames shown in contour; near Connecticut Farms, N. J. (N. J. Geol. Surv.)

chiefly composed was often irregular at the outset, and was subject to disturbance with every movement of the edge of the ice, so long as the ice and kames were in contact. The effects of the crowding of the ice are often distinctly seen in the disturbed and crumpled condition of the planes of stratification. The stratification was subject to still further disturbance when the ice melted, for in many cases

[1] Rept. State Geol. of N. J., 1892, p. 93, and Glacial Geology of N. J., p. 117.

the kame material, originally deposited against steep faces of the ice, must have slumped notably.

Much of the material entering into the make-up of kames had not been carried far, and was, therefore, not well water-worn. Not rarely its constituents retain glacial striæ. These characteristics of the material of kames gave rise to the descriptive designation "hillocks of angular gravel and disturbed stratification."[1]

Kames, developed at the edge of the ice during its advance, were over-ridden or destroyed as the ice pushed on over them; but kames developed at the edge of the ice at its most advanced stage and during its retreat, were not destroyed by the ice, and many of those formed in such situations by the later ice-sheets, and especially by the last, are still in existence.[2]

In regions of strong relief, ice often occupied deep valleys, after it disappeared from the intervening ridges. In such situations the ice sometimes seems to have lost vigorous motion, and drainage along its sides gave rise to deposits of stratified drift (Fig. 500), which after

[1] Am. Jour. Sci, Vol. XXVII, 1884, p 378.

[2] References touching Kames and Eskers: Hitchcock, Elementary Geology, 1857, pp. 260–3; Shaw, Ill. Geol. Surv., Vol. V (1873), pp. 107–110; Minn. Geol. Surv., Vol I (1884); Newberry, Geol. Surv., Ohio, Vol. II (1874), pp. 41–6; Vol. III, (1878), pp. 40–2; Lindemuth, ibid., p. 503; Upham, Proc. Amer. Assoc. Adv. Sci., 1876, pp. 216–225, Amer. Jour. Sci., Vol. XIV (1877), p. 459, Geol. of N. H., Vol. III (1878), pp. 3–176, and Amer. Geol, Vol. VIII (1891), p 321; Chamberlin, Geol. of Wis., Vol. II (1877), Third Ann. Rept. U S Geol. Surv, 1881–82, p. 299, and Amer. Jour. Sci., Vol. XXVII (1884), pp. 378–390; Cook, N. J. Geol. Surv. (1888), p. 116; Wright, Proc. Bos. Soc. Nat. Hist., Vol. XX (1878–80), pp. 210–220, and Ice Age in North America; McGee, Proc. Amer. Assoc. Adv. Sci., Vol. XXVII (1878), pp. 198–231, and Eleventh Ann. Rept. U. S. Geol. Surv., 1889–90; Stone, Proc. Bos. Soc. Nat. Hist., Vol. XX (1880), pp. 430–469, and Mono. XXXIV, U. S. Geol. Surv.; Dana, Amer. Jour. Sci., Vol. XXII (1881), pp. 451–468, Vol XXIII (1882), pp. 179, 360, and Vol. XXIV (1882), p 98; Hitchcock, Proc. Amer Assoc. Adv. Sci., Vol. XXXI (1884), p. 388; Lewis, Rept. State Geol. Surv. Penn., Rept Brit. Assoc. Adv. Sci., 1884, p. 720, and Proc. Phil. Soc Nat. Hist., 1885, pp. 157–173; Shaler, Proc. Bos. Soc. Nat. Hist., Vol. XXIII (1884), pp. 36–44, Ninth Ann. Rept. U. S. Geol. Surv. (1887–88), pp. 549–550, and Bull. Mus. Comp. Zool, Vol. XVI, pp. 203–5; Winchell, Minn. Geol. Surv., Vol. I (1884), pp 388, 665; Ells, Ann. Rept. Geol. Surv. Can. (1885), p. 653; Holst, Amer. Nat., Vol. XXII (1888), p 589; Crosby, Physical History of Boston Basin, 1889; Chapin, Trans. Meriden Sci. Assoc., Jan. 1891; Salisbury, Ann. Rept. N. J. Geol. Surv., 1891, pp. 89–92, and Glacial Geol. of N. J., 1902; Russell, Amer. Geol., Vol. XII (1893), p 232; Gulliver, Jour. Geol., Vol. I (1893), pp. 803–812; Davis, Bull. Geol. Soc Amer, Vol I, pp. 195–202, and Proc. Boston Soc. Nat. Hist., Vol. XXV., pp. 478–499; Bouvé, ibid., p. 173.

the melting of the ice, had somewhat the form of terraces, while their slopes and upper surfaces had something of the topography of kames.

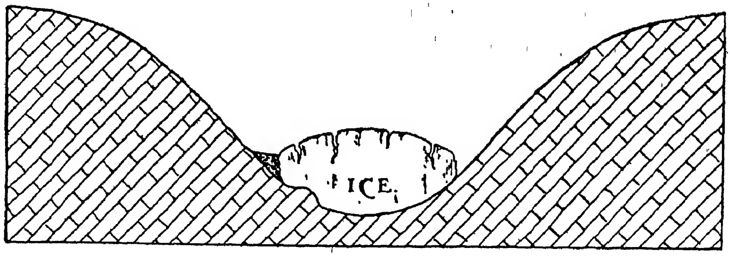


Fig. 500.—Diagram to illustrate deposition between stagnant or nearly stagnant ice, and the wall of the valley in which it lies.

Such terraces have been called *kame terraces*[1] (Fig. 501). This type of stratified drift finds abundant illustration in the Appalachian mountain region and in New England.

Fig. 501.—Diagram to illustrate kame terraces. *ABC* represents the stratified drift of the kame terraces which are underlain by ground moraine. Till also covers the valley bottom.

(2) **Beyond the edge of the ice.**—When the waters issuing from the ice found themselves in valleys, and when they possessed sufficient load and not too great velocity, they aggraded their valleys, developing *valley trains*,[2] which often extended far beyond the unstratified drift with which they were contemporaneous. Valley trains are usually associated with stout terminal moraines (Fig. 502). A protracted

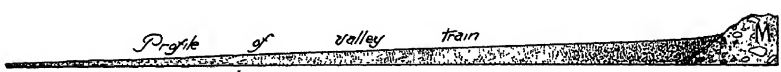


Fig. 502.—Diagram to illustrate the profile of a valley train and its relation to the terminal moraine in which it heads.

stationary stand of the ice-edge is as necessary for great aggradation of the valley below, as for the development of the terminal moraine.

[1] Salisbury, op. cit., pp. 156 and 121–124 respectively.

[2] 3d Ann. Rept. U. S. Geol. Surv., and Jour. of Geol., Vol. I, p. 534.

Valley trains often sustain significant relations to recessional moraines, as suggested by Fig. 503.

Where the water escaping from the ice spread over a plain instead of being concentrated in valleys, the deposits took on a form more like that of alluvial fans. By union, these fans often became extensive, and are known as *outwash plains, overwash plains, moraine plains, frontal aprons*, etc. They differ from valley trains much as alluvial fans differ from flood-plain deposits.

When the water which issued from the ice entered standing water it tended to develop *deltas*. Where the edge of the ice was long stationary, the deltas often attained great size. They sometimes merged laterally as alluvial fans do, giving rise to compound deltas, or

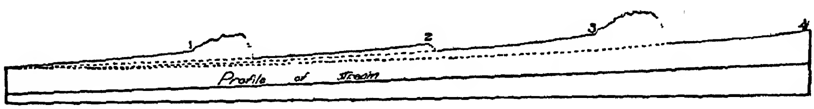


FIG. 503.—Diagram to illustrate the relations of imperfect valley trains to recessional moraines. The heads of the several trains are at 1, 2, 3, and 4. Examples of this relation are common in northern New Jersey.

subaqueous outwash plains.[1] Many such deltas are known about extinct lakes in the glaciated area of the United States, and about the borders of existing lakes, the levels of which have been lowered. The iceward edges of the deltas, like the iceward edges of outwash plains and valley trains, were sometimes in contact with the ice, and took on a kame-like phase. Deltas were also built into the sea at some points.[2]

Many of the valley trains, outwash plains, and deltas which developed beyond the edge of the later, and especially the last ice-sheet during the time of its maximum advance or during its retreat, are still well enough preserved to be readily identified, but they have little representation among the deposits left by the earlier sheets of ice. If they were well developed in the earlier glacial epochs, as they doubtless were in some cases, but apparently not in others, they have been largely removed by subsequent erosion. Valley trains, outwash plains, deltas, etc., developed during the advancing stage of an ice-sheet were over-

[1] The deltas about the extinct lake Passaic are an illustration. Ann. Rept. State Geol. of N. J, 1893, and Glacial Geol. of N. J.

[2] Stone, Mono. XXXIV, U. S. Geol. Surv., p. 371.

ridden and generally destroyed or obscured by the further advance of the ice.

Gradational types, pitted plains, patches of gravel and sand.[1]—Outwash plains sometimes depart from planeness by taking on some measure of undulation of the sag and swell (kame) type, especially near their iceward edges. The same is often true of the heads of valley trains. The heads of valley trains and the inner edges of outwash plains, it is to be noted, occupy the general position in which kames are commonly formed, and the undulations which often affect these parts of the trains and plains, respectively, are probably to be attributed to the influence of the ice itself. Valley trains and outwash plains, therefore, at their upper ends and edges, respectively, may take on some of the features of kames, and either may head in a kame area.[2]

Occasionally a morainic plain, or stratified drift in the general position of a morainic plain, is affected by numerous sags without corresponding elevations. This topographic type has received the name of *pitted plain*. The sags, in many cases at least, appear to be intimately connected with the ice-edge, and so to be marginal phenomena.

At many points near the edge of the ice during its maximum stage of advance, there probably issued small quantities of water not in the form of well-defined streams, bearing small quantities of detritus. These small quantities of water, with their correspondingly small loads, did not develop considerable plains of stratified drift, but small patches instead. Such patches have received no special designation.

When the waters issuing from the edge of the ice were sluggish, whether they were in valleys or not, the materials which they carried and deposited were fine instead of coarse, giving rise to deposits of silt or clay, instead of sand and gravel.

In the deposition of stratified drift beyond the edge of the ice, the latter was concerned only in so far as its activities helped to supply the water with the necessary materials.

(3) **Beneath the ice.**—Subglacial streams seem sometimes to have deposited gravel and sand in their channels. When the waters were

[1] Geol. of Wis., 1873–1880; Davis, Bull. Geol. Soc. Am., 1890, Vol. I, p. 195; Gulliver, Jour. of Geol , Vol. I, p. 803, and Glacial Geol. of N. J.

[2] Ann. Rept. State Geol. of N. J., 1892, p. 94.

not confined to definite channels, their deposits probably took on the form of irregular patches of silt, sand, or gravel; but where definite streams were confined to definite channels, their deposits were correspondingly restricted. When the channels remained constant in position for a long time, the aggradation may have been considerable. In so far as the channel deposits were made near the edge of the ice during the time of its maximum extension or retreat, they were likely to remain undisturbed during its melting, after which they stood out

FIG. 504.—An esker in Scandinavia, locality unknown.

as ridges. These ridges of gravel and sand are known as *osars* or *eskers* (Figs. 504 and 505). It is not to be inferred that eskers never originated in other ways, but it seems clear that this is one method, and perhaps the principal one, by which they came into existence.

Eskers early attracted attention, partly because they are relatively rare, and partly because they are often rather striking topographic features. They are often conspicuous, not so much because of their height, as because of their abrupt slopes and their even and narrow crests. They may be ten or several times ten feet high, but their crests are generally no more than a few feet wide. They are, for example, often so narrow, and their slopes so steep, that two wagons could with difficulty pass each other on their tops. The angle of their

slopes is about the angle at which the drift will lie. Where they cross marshes and swamps, as is sometimes the case, they are most conspicuous, sometimes resembling railway grades. Eskers no more than a fraction of a mile in length are more common than longer ones, but eskers scores of miles long are known. Long eskers sometimes wind up and down over low elevations and valleys, showing that the water which made them must have been under great head, if they

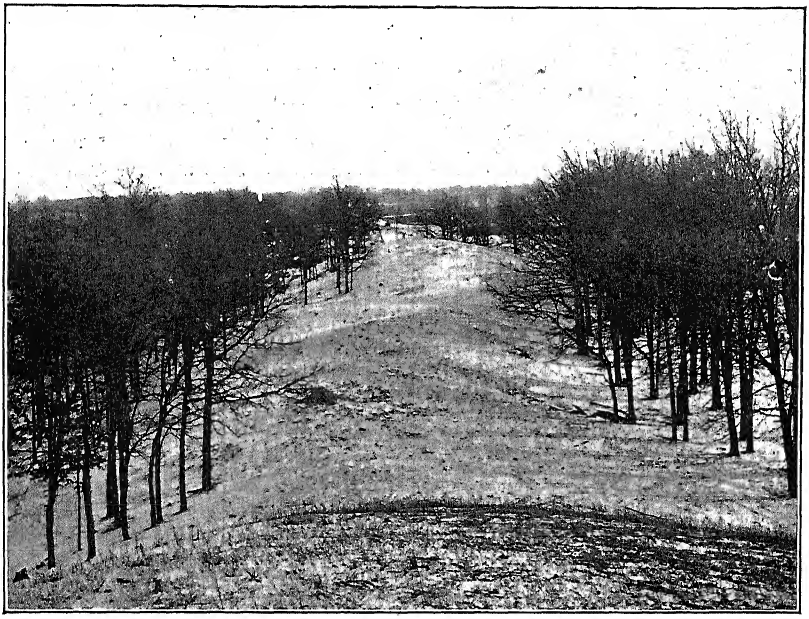


FIG. 505.—An esker 10 miles west of Aurora, Ill. (Bastin.)

are of strictly subglacial origin. They often lie along the lower slope of a valley, though distinctly above its bottom. Eskers are likely to be interrupted at intervals, probably at points where the depositing waters failed of confinement to definite channels, or their channels were too constricted, or had too high gradient to permit of deposition. The best-developed eskers in the United States are in Maine.[1]

Eskers are made up primarily of stratified gravel and sand. As in kames, the stratification is often much distorted, probably as the result of ice pressure. Bowlders are often present in them and on

[1] Stone, Mono. XXXIV, U. S. Geol. Surv.

their surfaces, showing the presence of the ice during their building. The bowlders might have been crowded in from the sides, or let down from the ice above. As in kames, the gravel is often not well rounded. Eskers often end in kames, and where they are interrupted, the interval is often occupied by kames. Occasionally they end in deltas, where the constructing stream issued from the ice into a lake, or in alluvial fans, where the stream issued upon a plain.

Most existing eskers were probably made just before the disappearance of the ice from the region where they occur. Eskers made during the advance of an ice-sheet were likely to be destroyed at a later time. Probably most eskers were made by streams flowing essentially parallel to the direction of the ice movement. The deposits of streams in other positions would stand much less chance of developing distinct ridges before being destroyed by the movement of the ice.

It is probable that kames are sometimes developed beneath the ice. It has been noted that eskers are occasionally interrupted, probably both where the channels of the subglacial streams suffered constriction, and great leakage. It is now to be added that kames are sometimes developed at the point of interruption. Irregular and ill-defined patches of sand and gravel, instead of kames, often occur where the eskers are broken.

(4) **Deposits of superglacial and englacial streams.**—Superficial and englacial streams have been supposed to make deposits in their channels. It has even been conceived that this was the principal mode of origin of eskers. Against this view, and against the view that superglacial stream deposits are of consequence quantitatively, stand two facts. (1) So far as known, the surfaces of ice-sheets are free from drift (apart from wind-blown dust) except for a fraction (and generally a small one) of a mile from their edges;[1] and (2) superficial streams are, in general, much too swift to allow of the accumulation of drift in their channels. The channels of most superficial streams in North Greenland, *even near the edge of the ice where surface débris is abundant,* are free from drift. Judging from the force with which they issue from the ice, englacial streams are likewise much too swift to allow of deposition along their channels, as a general rule.

Such trivial accumulations of drift as may be made in superglacial

[1] Jour. of Geol., Vol. IV, p. 804.

or englacial channels would ultimately reach the land surface. During the advance of the ice they would be delivered onto the land, as the ice which sustained them melted from beneath. They would then be over-ridden by its further forward motion. During the retreat of the ice, such deposits, once they reached the land surface, would not be subsequently destroyed or overridden by it.

Relations of Stratified to Unstratified Drift.[1]

The general relations of the stratified to the unstratified drift have already been indicated in a general way. These relations may be understood, when it is remembered (1) that the edge of each ice-sheet probably oscillated back and forth, more or less, during both its advance and its retreat, (2) that there were several ice-sheets over large parts of the area affected by drift, and (3) that stratified drift was being deposited at all stages of every ice-sheet, at points (*a*) beneath the ice, (*b*) at its edge, and (*c*) beyond it.

On the basis of position, existing stratified drift deposits may be classified as follows:

1. **Extraglacial deposits,** made by the waters of any glacial epoch if they deposited beyond the farthest limit of the ice.

2. **Supermorainic deposits,** made chiefly during the final retreat of the ice from the locality where they occur, but sometimes by extra-glacial streams or lakes of an epoch later than that when the subjacent till was deposited. Locally, too, stratified deposits of an early stage of a glacial epoch, lying on till, may have failed to be buried by the subsequent passage of the ice over them, and so remain at the surface. In origin, supermorainic deposits of stratified drift were for the most part extraglacial (including marginal), so far as the ice-sheet calling them into existence was concerned. Less commonly they were subglacial, and failed to be covered, and less commonly still (if ever) superglacial.

3. **Submorainic (basal) deposits** were made chiefly by extraglacial waters in advance of the first ice which affected the region where they occur. They were subsequently overridden by the ice and buried by its deposits. Submorainic deposits, however, may have arisen in other ways. Subglacial waters may have made deposits of stratified

[1] Jour. of Geol., Vol IV, pp. 948–970.

drift on surfaces which had been covered by ice, but not by till, and such deposits may have been subsequently buried. The retreat of an ice-sheet may have left rock surfaces free from till, on which the marginal or extra-marginal waters of the retreating ice, or of the next advancing ice, may have made deposits of stratified drift. These may have been subsequently covered by till during a re-advance of the ice in the same epoch, or in a succeeding one. Still again, till left by one ice-sheet may have been completely worn away locally before the next ice advance,

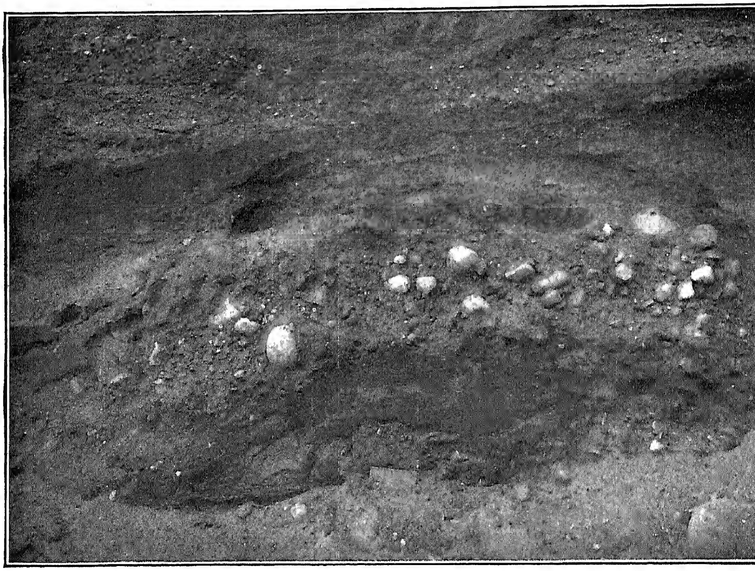


FIG. 506.—Diagram showing the intimate association of stratified and unstratified drift.

so that stratified deposits connected with a second or later advance may have been made on a driftless surface, and subsequently buried.

4. **Intermorainic stratified drift** may have originated at the outset in all the ways in which supermorainic drift may originate. It became intermorainic by being buried in some one of the various ways in which stratified drift may become submorainic.

Topographic distribution of stratified drift. — Though stratified drift is most abundant in valleys and lowlands, it is not confined to these positions. Kames are measurably independent of valleys and lowlands, and though eskers often show a tendency to follow valleys,

they often disregard topography to the extent of crossing ridges and uplands a few hundred feet in height (200 to 400 feet in Maine[1]). Kame-terraces and deltas, also, are often well above the bottoms of the depressions with which they are associated.

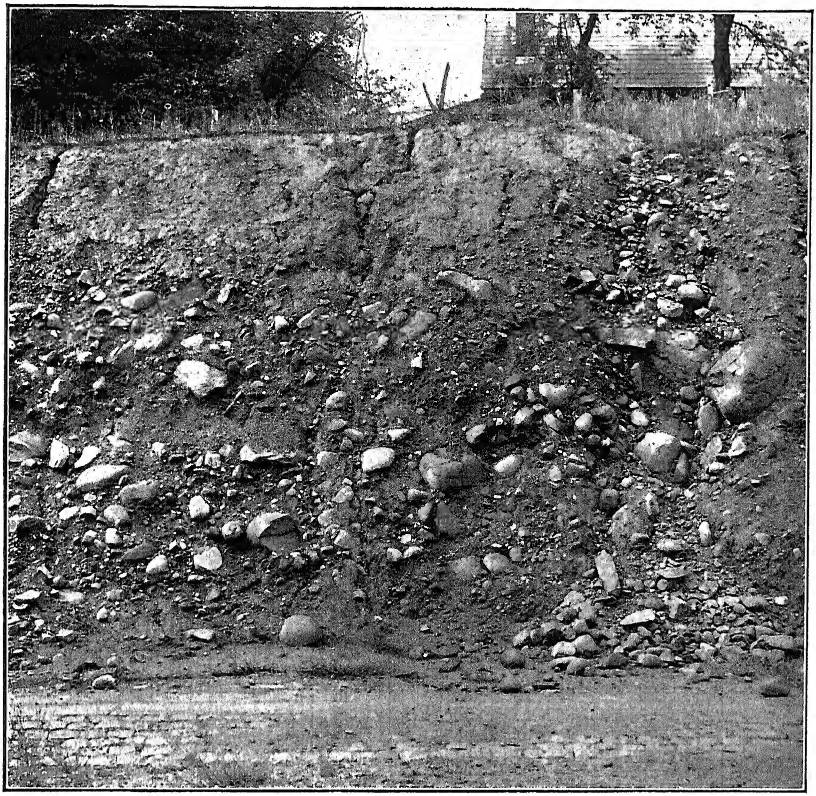


FIG. 507.—Section of glacial drift which, though not stratified, was largely worked over by water. The stones are water-worn rather than glacier-worn. Northeast part of Newark, N. J. (N. J. Geol. Surv.)

Changes in Drainage Effected by Glaciation.

The great and unequal erosion of the ice-sheets, and especially the great and unequal deposition of the drift, produced a profound effect upon the topography of the planer parts of the area affected by glaciation. One of the conspicuous results of this alteration of the topography was the derangement of the drainage. One of the results is seen

[1] Stone, Mono. XXXIV, U. S. Geol. Surv., p. 434.

in the thousands of lakes which affect the surface of the later drift, and to a less extent, the surface of the older. The basins of these lakes or ponds arose in various ways. There are (1) rock basins produced by glacial erosion; (2) basins produced by the obstruction of river valleys by means of the drift; (3) depressions in the surface of the drift itself; and (4) basins produced by a combination of two or more of the foregoing. The third class, as above, may be subdivided into depressions in the surface of (*a*) the terminal moraine, (*b*) the ground moraine, and (*c*) stratified drift. Since the stratified drift in

FIG. 508.—Diagram illustrating normal drainage in the driftless area of Wisconsin and Illinois.

which the lakes of this last sub-class lie is largely in valleys, it would not be altogether inappropriate to class some of them with group (2).

In addition to the lakes and ponds now in existence, there have been others of a more temporary character. Some of them have already become extinct by reason of filling or by the lowering of their outlets since the ice melted; others depended for their existence on the presence of the ice, which often obstructed valleys, giving rise to basins.[1] The ice also developed basins outside of valleys, when the surface slope was favorable.

[1] For examples of such lakes, see Glacial Geology of N. J., pp. 151–159, and Fairchild, Bull Geol. Soc. Am., Vol. X, pp. 27–68, and Stage XII following.

Another result is to be seen in the changes in the courses of the streams. In many cases, pre-existing valleys were filled with drift, so that when the ice melted the old channels were obstructed at many points, and surface drainage was forced into courses which were partly new. In other cases, the ice, by encroaching on the middle course of the valley, as in the case of the Ohio, forced drainage around its front,

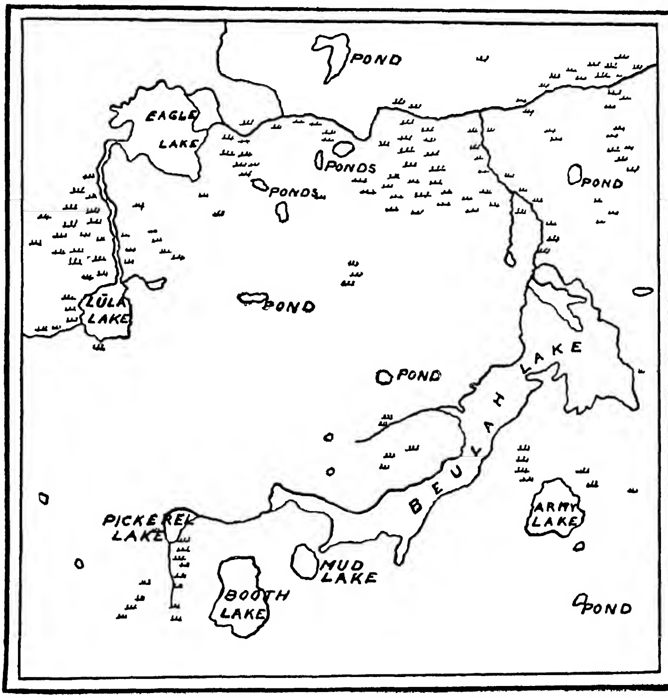


FIG. 509.—Diagram illustrating characteristic drainage in the glaciated area of southeastern Wisconsin.

and the drainage lines thus established by force, were often held after the ice melted.

There are few streams of great length in the area covered by the ice, which were not turned from their old courses for greater or less distances by the ice or the drift. The Mississippi, the Ohio, and the Missouri, the master streams of the United States within the glaciated area, and a host of their tributaries, as well as many streams tributary to the St. Lawrence, suffered in this way. The history of some of these changes has been studied in detail,[1] but the history of the

changes is often difficult of reading. The outlines of drainage basins, as well as the courses of individual streams, were often affected.

One of the characteristics of streams which have been thus deranged is found in the lack of harmony between different parts of their valleys. Within the glaciated area a stream often flows in a capacious preglacial valley, then in a narrow post-glacial gorge of wholly different aspect, whence it may emerge again into another section like the first. Most streams whose courses were modified by the ice or its deposits afford illustrations.

Again, preglacial valleys, even valleys of considerable length, were sometimes filled completely, so that their courses are only known, so far as they are known, by borings, which reveal the great depth of the drift, and of the old channel. Many stream valleys, in the areas of heavy drift, are wholly postglacial, showing the completeness with which the old drainage lines were sometimes effaced.

The Succession of Ice Invasions.

It was formerly thought that there was but a single ice invasion of brief duration, followed by a rapid retreat attended by great floods arising from the melting of the ice; but the more careful studies of later years have revealed a series of invasions separated by very considerable intervals. It is not yet known how far the ice retreated in the intervals between the advances, but there is convincing evidence that some of the intervals were long, much longer than the period which has elapsed since the last ice retreated. There is also good evidence that in some of them the climatic conditions became at least as mild as they are today. While there are differences of view with reference to the entire disappearance of the ice-sheet from the plains of Labrador and Keewatin, and respecting the

[1] For changes in the Mississippi and in the rivers of Illinois, see Leverett, Mono. XXXVIII, U. S. Geol. Surv., Chapter XII. For changes in the Upper Ohio, see Chamberlin and Leverett, Am. Jour. Sci., Vol. XLVII, 1894 (contains references to earlier work of Carll, Chance, White, Stevenson, Lewis, Wright, Lesley, Spencer, Randall, and Foshay, in the same region). For changes in the Erie and Ohio Basin, see Leverett, Monogr. XLI, U. S. Geol Surv., Chap. III, and Tight, Professional Paper, No. 13, U. S. Geol. Surv., and for changes in the course of the upper Missouri and its tributaries, see Todd, Science, Vol. XIX, p. 148 (1892), Geol of S. Dak., pp. 128 and 130 (1899), and Bull 144, U. S. Geol. Surv. Changes in drainage in New York have been summarized by Tarr, Phys. Geol of New York, 1902, with references to earlier literature.

estimate to be put upon the importance of the interglacial intervals, the above statements are fully justified by the data now accumulated. Besides the greater advances and retreats, there were numerous halts or oscillations which probably affected the oncomings as well as the retreats of the ice.

The proofs of the interglacial intervals and the evidences of their duration are found in the surface changes which were wrought by drainage after the deposition of one sheet of drift, and before the deposition of the next, in the depths to which earlier sheets of drift were leached and oxidized by weathering before the deposition of later ones upon them, in the accumulations of peat, soil, etc., now found between different sheets of drift, and in some cases in the changes of topographic attitude which intervened between the deployment of successive ice-sheets.[1]

The following are the American stages of the glacial period now recognized in the interior of North America, numbered in the order of their age:

XIII. The Champlain sub-stage (marine).
XII. The glacio-lacustrine sub-stage.
XI. The Later Wisconsin, the sixth advance.
X. The fifth interval of deglaciation, as yet unnamed.
IX. The Earlier Wisconsin, the fifth invasion.
VIII. The Peorian, the fourth interglacial interval.
VII. The Iowan, the fourth invasion.
VI. The Sangamon, the third interglacial interval.
V. The Illinoian, the third invasion.
IV. The Yarmouth, or Buchanan,[2] the second interglacial interval.
III. The Kansan, or second invasion now recognized.
II. The Aftonian, the first known interglacial interval.
I. The sub-Aftonian, or Jerseyan, the earliest known invasion.

These stages were by no means equal, the earlier being markedly longer than the later. There was something like a geometrical gradation from the earliest and longest to the latest and shortest.

[1] Distinct glacial epochs and the criteria for their recognition, Jour. of Geol., Vol. I, pp. 61–84.

[2] The Buchanan gravels lie between the Kansan and Iowan drift-sheets, in localities where the Illinoian is not present, and hence it is not quite certain what interval is represented by their deposition.

I. **The sub-Aftonian, or Jerseyan, glacial stage.**—In Iowa there is found a very old drift-sheet lying beneath the Kansan drift-sheet, with sand and gravel, peat, old soil, and other products of an ancient surface between them. It is not now known that this sub-Aftonian drift-sheet comes to the surface, except as exposed by erosion, in Iowa or other parts of the Keewatin area, and it is not yet certain whether the oldest portions of the Labradorean drift are to be correlated with it or not. It is reasonable enough in itself to believe that the earliest ice invasion may not have pushed as far southward as a later one, and such a view is held relative to the earliest glacial formation of Europe.[1] In Pennsylvania[2] and New Jersey,[3] the frayed edge of a very old sheet of drift emerges from beneath the much later drift of the region, and this older drift may not improbably be the equivalent of the sub-Aftonian of Iowa, but as direct connection cannot be traced, the correlation is uncertain.[4] The sub-Aftonian is a typical sheet of till notable for the relatively high percentage of its greenstone erratics. It is exposed by erosion, or artificially, near Afton, at Oelwein, and at other points in Iowa, and probably embraces nearly all the sections of "lower till" cited by McGee in his paper on the drift of northeastern Iowa.[5]

II. **The Aftonian interglacial stage.**—Overlying this till sheet at many points is a stratum of sand and gravel, and at some points beds of peat and muck, with stumps and branches of trees, together with the physical indications of an interval of erosion and weathering. It is not wholly clear whether the assorted drift constituted the glacio-fluvial products of the closing stage of the sub-Aftonian ice epoch, or was derived by secondary action from the drift during the interglacial interval. In the typical localities between Afton and Thayer, Iowa, the deposit contains bowlders of till, showing that it is truly secondary, but this does not define its precise age. In some districts assorted drift is sufficiently prevalent and continuous at this horizon to give rise to local systems of flowing wells. Near the typical locali-

[1] Geikie's Ice Age, 3d ed., and Jour. Geol, Vol. III, p. 241.

[2] Williams, E, Proc. Am. Phil. Soc., Vol. XXXVII (1898), p. 84.

[3] Salisbury, Annual Report of State Geol. of N. J, 1893.

[4] The Albertan drift (province of Alberta, Can.), formerly thought to be the probable equivalent of the sub-Aftonian, is probably not of glacial origin. Calhoun, unpublished data.

[5] Eleventh Ann Report U. S. Geol. Survey.

ties named, great masses of this assorted material were plowed up by the succeeding Kansan ice-sheet and incorporated in its till, as shown in Fig. 511. The organic remains in the interglacial beds seem to imply a cool temperate climate, but as a cool temperate stage must be passed through twice in every transition from a glacial climate to a warm one and back again, organisms indicating a cool climate

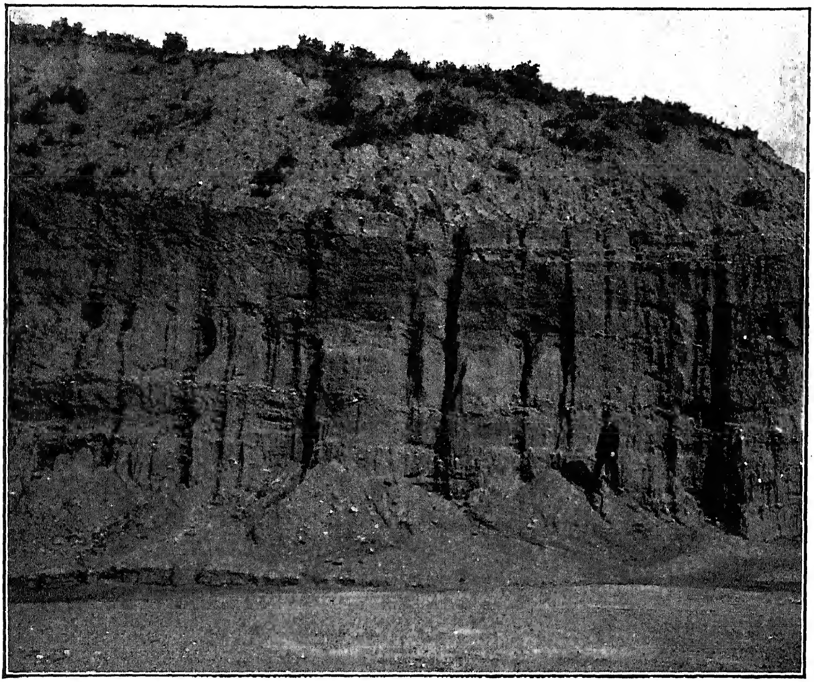


FIG. 510.—Section of drift at Thayer, Union County, Ia. The stratified drift below, making up the larger part of the section, is Aftonian. It is overlain by Kansan till. (Calvin, Iowa Geol. Surv.)

do not necessarily show how great an amelioration may have been reached, unless the record is known to be complete. The length of the Aftonian interval has not been well determined, from lack of adequate accessibility, but it was at least a notable interval. The pebbles are much decayed and the soils, peat, etc., imply a considerable lapse of time.

The old drift in western Pennsylvania doubtfully referred to the sub-Aftonian stage is in somewhat like manner associated with impor-

tant gravel deposits, and streams of valley gravels stretch far down the drainage courses that then led away from the ice-edge. This is notably true of the Allegheny and Ohio valleys. These old glacial gravels are so related to the present trenches of these streams as to seem to imply a channel erosion of 200 feet and more since their deposition,[1] though this interpretation has been questioned.

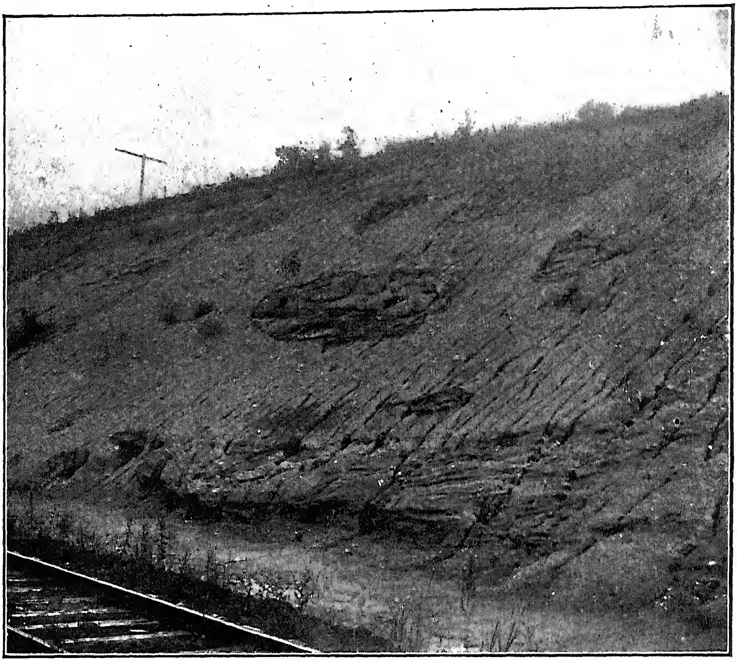


FIG. 511.—Section ¼ mile west of Thayer, showing masses of Aftonian gravel included in the Kansan till. The most conspicuous mass is near the center of the figure. The masses of gravel thus included are not cemented, and it is thought that they must have been plowed up and included while in a frozen condition. The basal part of the section at the right is Aftonian. (Calvin, Ia. Geol. Surv.)

The products of the glacial waters of this stage in eastern Pennsylvania and New Jersey were commingled with non-glacial wash-products and will be discussed under the non-glacial formations (Columbia, p. 447).

The Natchez formation.—At Natchez, Mississippi, there is a section of assorted material about 200 feet in thickness which is chiefly made up of derivatives from

[1] Leverett, Mono. XLI, U. S. Geol. Survey, p. 235.

the Lafayette formation, upon which it rests unconformably (Fig. 513); but it also contains crystalline pebbles and calcareous clays assignable to wash from the glacial regions, all other assignments seeming to be excluded by a special investigation. A marked interval between its deposition and that of the overlying loess is indicated. As the sub-Aftonian and Aftonian deposits are the only older ones with which great gravel deposits are known to be associated, and as the Natchez deposit must be referred to an early Pleistocene stage because the great Mississippi trench, 60 miles more or less in breadth, has been

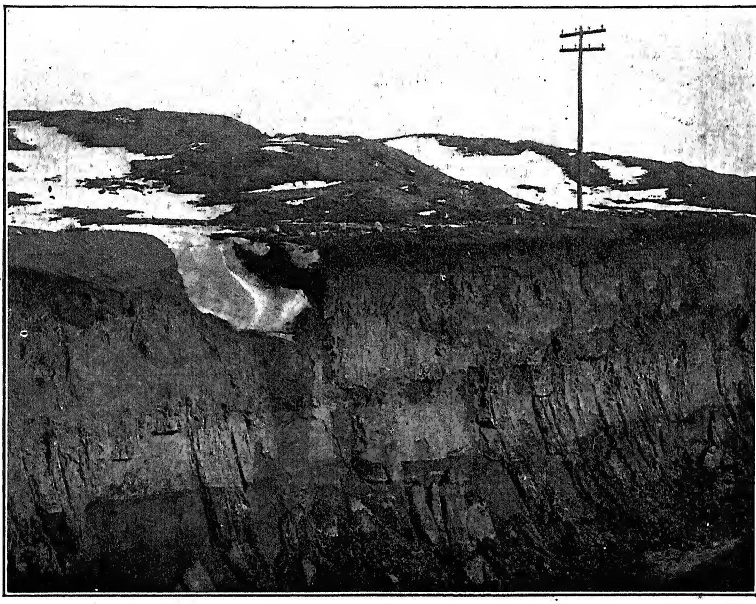


FIG. 512.—Section just east of Oelwein, Ia. 1, Sub-Aftonian (Jerseyan); 2, Aftonian; 3, Kansan; and 4, Iowan.

excavated since it was formed, reference to one of these two stages is more plausible than to any later one. This reference is strengthened by the fact that almost the whole formation—which was clearly a valley train leading back to the drift area—has been removed.

Assuming the correctness of this reference and combining it with other data, the following tentative conception of the sub-Aftonian and Aftonian stages is reached. The ice-sheet spread from the Keewatin and Labradorean centers to the approximate limit of the known drift in the Mississippi valley, and deposited a typical sheet of bowlder clay (sub-Aftonian) and also gave rise to great valley trains of glacio-fluvial material that stretched from the drift border to the Gulf, filling the low-gradient valleys of the time to depths of 30 to 50 feet near the drift border, and of 200 feet near the Gulf (Natchez formation). The invasion

of the ice blocked up many northward trending valleys and caused their streams to find new courses along the ice border. The present Ohio and Allegheny rivers seem to have been formed by the union of several streams that previously flowed into the Erie basin. The Missouri river seems to have been formed by a similar combination of many streams that previously flowed northerly and easterly, but some part of this readjustment of the drainage seems to have been later

FIG. 513.—The unconformity between the Natchez above and the Lafayette below. The line of contact is indicated by the dotted line.

than this stage. Including these later changes, the Ohio and Missouri rivers may be pictured as two great drainage arms embracing the border of the ancient ice-sheet and carrying away its waters. Rather low gradients and a low elevation in the lower Mississippi seem thus to be indicated.

III. **The Kansan glacial stage.**—As defined by Calvin, Bain, and others who have specially studied it,[1] the Kansan stage is represented by a typical sheet of till occupying a large surface area in Kansas, Missouri, Iowa, and Nebraska (Fig. 470), and theoretically extending

[1] Reports of the Iowa Geol. Survey.

under the later glacial formations to the northward as far back as the Keewatin center of radiation. Much of this sheet of drift, as originally developed, has probably been rubbed away by later glaciations. Presumably a similar sheet was formed by a contemporaneous ice movement from the Labradorean center, but this has not been certainly identified in the region east of the Mississippi. It probably fell short of the later advances there, and lies concealed beneath their débris, so far as it has escaped destruction. The Kansan formation is a pronouncedly clayey till, with exceptionally little assorted drift. Glacial water action seems to have been notably inefficient. Observation on this and the succeeding glacial formations has forced the abandonment of the earlier conception of vast floods as the inevitable accompaniment of the ice-melting, the meagerness of marginal drainage in some cases being one of the strangest of all the strange phenomena of the glacial period. No great deposits of sand and gravel have been found in, or on, or leading away from the edge of this formation.

Originally the surface of the Kansan till sheet seems to have been rather plane, but it has since been markedly eroded, and bears clear evidence of great age as compared with the latest drift. As the next younger sheet (Illinoian sheet) of drift overlaps its east border near the Mississippi (Fig. 514), comparison along the junction shows that a large part of the erosion of the Kansan drift took place before the superposition of the Illinoian drift. A long intervening epoch is therefore inferred, an inference strengthened by the deep weathering of the Kansan drift, and the pronounced decay of its bowlders.

IV. **The Yarmouth interglacial stage.**[1]—The erosion just mentioned is perhaps the best evidence of a prolonged interval between the Kansan and Illinoian ice invasions; but in the tract where the Illinoian till sheet overlaps the Kansan, in eastern Iowa, an old soil with deep subsoil weathering is found to have developed on the surface of the latter before its burial. Some vegetable accumulations have also been preserved, a good instance being found near Yarmouth, Iowa, whence the name was taken. Bones of the rabbit and skunk have been identified from this horizon. A climate not essentially different from the present is inferred.

[1] Leverett, Mono XXXVIII. U S Geol. Survey

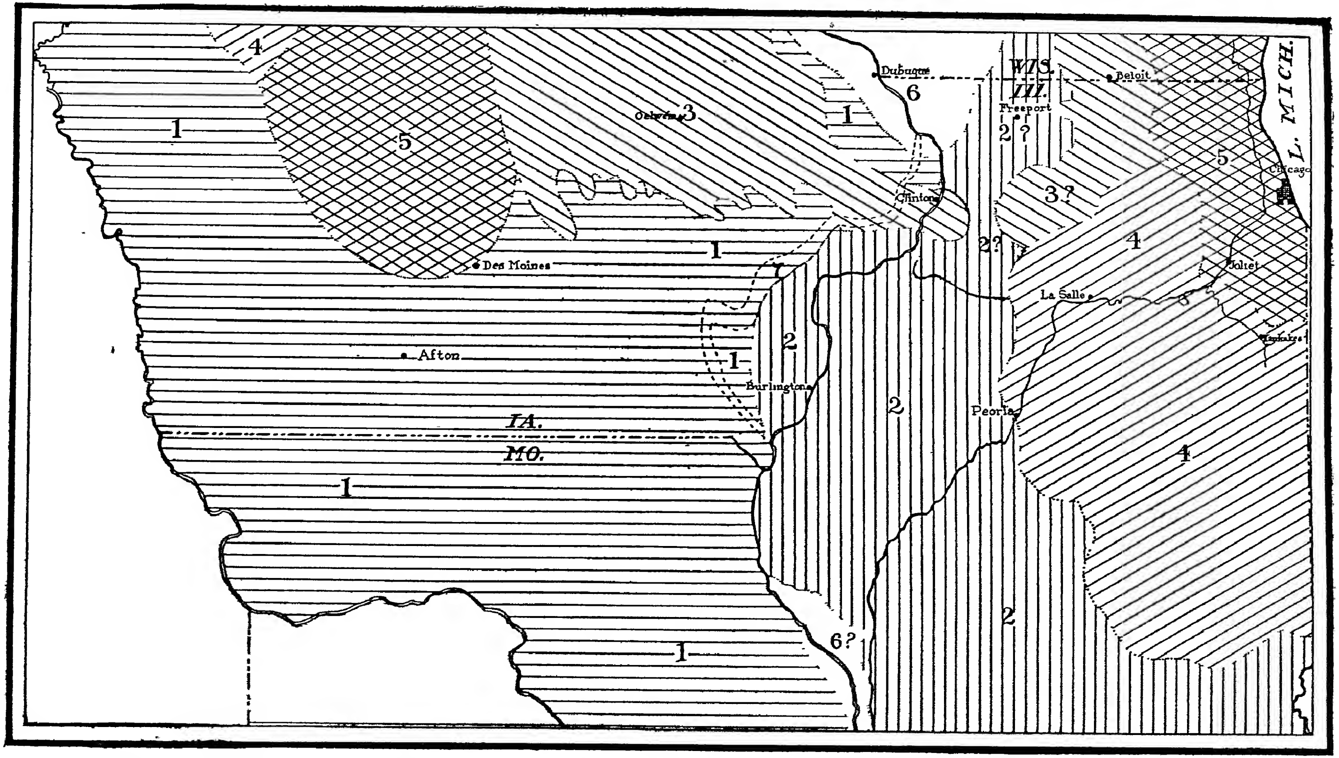


Fig. 514.—Map showing the relations of the several drift-sheets in Iowa and northern Illinois. 1. Kansan; 2. Illinoian; 3. Iowan; 4. Early Wisconsin; 5. Late Wisconsin; 6. Driftless area; 7. Course of the Mississippi during the Illinoian glacial epoch. (After Leverett, U. S. Geol. Surv., and Calvin, Ia. Geol. Surv.)

V. **The Illinoian glacial stage.**—The typical formation of this stage was a sheet of till occupying the surface in the southern and western portions of Illinois (Fig. 514), and running back under the later formations to the northeast toward the Labradorean center of radiation. Its surface exposure is traceable northerly into Wisconsin and easterly into Indiana and Ohio, but it is not identified with any confidence farther east, where the margin seems to have fallen back, and to have been overridden by the ice of the Wisconsin epoch. The identification of the Illinoian drift in the Keewatin area is yet an open question. Like the Kansan drift, the Illinoian is made up of clayey till, without marked association with assorted drift in most regions. There is appreciably more assortment of the material, however, than in the Kansan drift. There are tracts of kames in some sections, notably a belt running southwest from Tower Hill, Illinois, to the margin of the drift. The original surface was generally plane, and only a limited tendency to ridging in the fashion of terminal moraines has been found. The west edge of the Illinoian ice-lobe crossed the present course of the Mississippi between Rock Island and Fort Madison, and pushed out into Iowa a score of miles, forcing the river in front of it.[1] Previously, the Kansan lobe had invaded the border of Illinois, and probably forced the Mississippi east of its present course, if indeed it did not already have a course east of its present one before the Kansan ice appeared. Efforts to trace out the early courses of the Mississippi under the thick mantle of drift in Illinois have not been entirely successful.

VI. **The Sangamon interglacial stage.**[2] — Like the preceding interglacial stages, this is characterized by peat, muck, old soil and subsoil, weathering, surface erosion, etc. Judged by these, the interval was not as long as the Yarmouth.

VII. **The Iowan glacial stage.**[3]—The Iowan ice invasion is recorded in a thin sheet of till (Fig. 512), marked by an exceptional profusion of large granitoid bowlders which lie chiefly on the surface and are somewhat aggregated into a bowlder belt on the eastern border of the tract. The typical Iowan drift was formed by a lobe of the Keewatin ice-sheet, occupying the north-central part of Iowa (see map, Fig. 514). It fell much short of the Kansan invasion of the same

[1] Leverett, Mono. XXXVIII, U. S. Geol. Survey.

[2] Idem.

[3] See Calvin, Bain, and others, Reports Iowa Geol. Surv.

region. A drift sheet in northern Illinois, apparently much younger than the recognized Illinoian, has been tentatively regarded as the Labradorean equivalent of the typical Iowan, but this view is not held very firmly. As with the Kansan and Illinoian, the tendency to morainic ridging was very feeble. The outwash from the border was also scant, unless the loess silt represents it, in which case the drainage must have been extremely gentle. While the loess is not confined to this stage, and probably not to the glacial regions even, the chief loess formation of the immediate Missouri and Mississippi basins seems to be approximately of Iowan age. The loess will be considered later. Fig. 514 shows the relations of the several drift sheets in Iowa and Illinois.

VIII. **The Peorian interglacial stage.**[1]—This is characterized in the same way as the preceding interglacial intervals, but less strongly, and obviously represents a less important epoch. The interglacial fossiliferous beds near Toronto, referred to later, have been assigned to this stage, but they may, perhaps, be older.

IX. **The Earlier Wisconsin glacial stage.**—The formations of the two Wisconsin stages together occupy much larger surface areas than the preceding, because they were not overlapped by later drifts, and they are hence less modified. Besides this, they seem to have had stronger features originally. The till-sheets are marked not only at their borders, but at intervals in the oscillatory recession of the ice, by declared terminal moraines. Kames, eskers, drumlins, and other special forms of aggregation and of outwash mark the surface, and reveal the mode of action of the ice and the glacial waters in a conspicuous way, and are in contrast with the nearly expressionless surfaces of the older sheets of drift. A part of this difference is due to the greater freshness of the Wisconsin formations; but the larger part, apparently, is assignable to a stronger original expression. This is more markedly true of the later Wisconsin drift than of the earlier. At least three successive terminal morainic tracts characterize that portion of the Early Wisconsin formation in Illinois which was not covered by the Late Wisconsin. The outermost of these lies on the border of the Wisconsin drift, and marks the outermost limit of the ice; the others lie within this outermost belt, and are rudely concentric with it, marking stages of halt, or of minor advance in the general oscillating retreat of the ice.

[1] Leverett, op. cit.

X. **The fifth interval of recession.**—There was an interruption of the retreat of the earlier Wisconsin ice at some unknown line within the area of the later drift, followed by a re-formation of the ice-lobes, and a re-advance of the ice-front. It does not appear that this interval was very long, but it was sufficient to permit the lobes of the ice-sheet to change their relative sizes and their relations to one another to such an extent that the moraines of the later stage at some points cross those of the earlier at large angles. It is uncertain whether the interval should be put in the preceding class, as the shortest representative of a declining series, or referred to a different category, and it has been left unnamed.

XI. **The Later Wisconsin glacial stage.**—Following this epoch of re-adjustment, the ice margin assumed a pronounced lobate form, and gave rise to the most declared moraines, drumlins, and other distinctive glacial formations of the period. The ice radiated not only from the Labradorean, Keewatin, and Cordilleran centers (Fig. 469), but from many isolated heights. Nearly all the well-known mountain glaciation of the west is referred to this epoch. The drift-sheet of this stage is characterized by enormous terminal moraines, by great bowlder belts, by unusual developments of kames, eskers, drumlins, outwash aprons, valley trains, and other diagnostic features of glacial action and glacio-fluvial coöperation. This drift-sheet, far beyond all the others, bears the stamp of the great agency of the period. The disposal of the ice in great lobes is referable to the influence of the great basins. Field studies indicate that broad, smooth-bottomed basins, elongate in the general direction of the ice movement, favored the prolongation of the ice into broad lobes, while sharp, deep valleys of tortuous course or transverse attitude had little effect upon the extension of the ice. A study of the accompanying map (Fig. 470) will make clear the relation between the great ice-lobes and the broad, smooth valleys lying under or back of them.

The Later Wisconsin drift is characterized in some places[1] by nearly a score of concentric moraines which, in some cases, represent re-advances of the ice in the course of its general retreat, and in others perhaps nothing more than halts sufficient to permit an exceptional accumulation of drift at the ice border. There appears to have been

[1] Minnesota, Upham, 9th Ann. Rept. Geol. and Nat. Hist. Surv. of Minn , 880; Leverett, Mon. XLI, U. S. Geol. Surv.

exceptional vigor of ice action, correlated with rapidity of melting, resulting in a sharp contest between the antagonistic agencies that made for advance and retreat. The older drift-sheets, so far as overridden by the ice of this epoch, were cut away more largely than in preceding epochs, and the scoring of the rocks below was more prevalent and profound. This was notably so in the great thoroughfares of movement, and for obvious reasons less so where the lateral borders of the lobes only lapped upon the older drift. Extensive overriding of the older drift, without complete removal, occurred in some districts, notably in Illinois and Michigan, as determined by Leverett.

All of these several sheets of drift have never been seen in superposition and the history sketched is based on the relations of the sheets of drift at different points.[1] Theoretically, and perhaps really, the

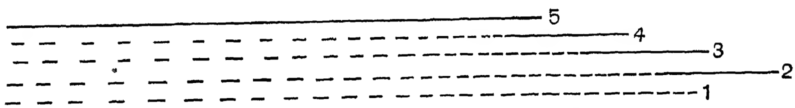


FIG. 515.—Diagram illustrating the imbrication of the successive sheets of drift. The full lines represent the portion of the drift-sheets not overspread, or but little overspread, by later ice-sheets, the broken lines represent the portions of the successive drift-sheets which were covered by ice at a later time. 1 corresponds to Jerseyan or sub-Aftonian, which in general is less extensive than the Kansan, though locally, as in New Jersey, it extended farther south than any other. 2 represents the Kansan drift, the southern margin of which is not covered by younger drift. 3, 4, and 5, respectively, represent the Illinoian, Iowan, and Wisconsin sheets of drift.

several sheets of drift are imbricated as shown in Fig. 515; but each sheet of drift is discontinuous beneath the overlying one, and this discontinuity goes so far that beneath the Wisconsin drift, for example, the several sheets are more commonly wanting than present. Fig. 515 gives diagrammatic expression to the conception here presented.

XII. **The glacio-lacustrine sub-stage.**—In the course of the retreat of the ice of the later Wisconsin epoch, a complex series of pondings of water between the ice-border and the higher land fronting it took place, particularly in the St. Lawrence basin, giving rise to a succession of temporary, constantly changing lakes, with shifting outlets. This was but an episode of the Later Wisconsin glacial stage, but it constituted a special phase of action, and merits recognition because of its individuality.

[1] Jour. of Geol., Vol. I, pp. 61–84. An exposition of the criteria for the recognition of distinct glacial epochs.

As the ice border withdrew to the north of the divide separating the St. Lawrence basin from the Mississippi basin, the glacial waters were ponded between the ice on the north and the divide on the south. To find escape across the divide, the waters were compelled to rise to the heights of the lowest available cols. At first, nearly every considerable depression in the divide to the south was occupied by a discharging stream, and the ponded water to the north formed innumerable small lakes.[1] But as the ice retreated farther into the basin, the sizes of the lakes tended to increase as their basins were enlarged; but at the same time the ponded waters tended to unite along the edge of the withdrawing ice, and to utilize only the lower passes across the divide to the south. This tended to lower the lakes, and hence to reduce them. There thus followed a complex series of antithetical changes resulting in the making and unmaking of lakes. This continued until the obstructing ice withdrew from the axis of the St. Lawrence basin. The last of the shifting series of ice-ponded lakes of this basin then disappeared, leaving the present rock-bound lakes as their successors. The full details are too voluminous for introduction here, but a brief sketch of the history of the leading lakes will indicate the nature of the changes which took place.

When the end of the Lake Michigan ice-lobe withdrew a little within the Lake Michigan basin, a crescentic belt of water formed about its southern extremity, and found a point of discharge into the Illinois valley through a col southwest of Chicago, which it proceeded to erode to greater depths. This valley has since become the site of the Chicago drainage canal.[2] A glacial lake (the extinct Lake Chicago) was thus initiated, and as the ice-lobe withdrew, the lake gradually extended northward (Fig. 516).

A similar lake was formed about the head of the Lake Superior ice-lobe, and discharged through an outlet at the head-waters of the Brule and St. Croix Rivers to the Mississippi. Another lake of like origin (Lake Maumee) was formed about the end of the Erie ice-lobe, and discharged its waters by way of Fort Wayne into the Wabash, and thence to the Gulf.

[1] For local lakes in New York, see Fairchild, Bull. Geol. Soc Am., Vol. X, pp. 27–68.

[2] This valley appears to have served a similar function in earlier stages of glacial retreat, but it was not the preglacial outlet of the Lake Michigan basin, as there are much lower channels (now buried) both north and east of it.

As the ice-lobe that lay in the Erie basin retreated, the crescentic Lake Maumee at its end expanded, one horn extending eastward on the southern border of the lobe, and the other northward on the northwestern border, until the latter found a pass along the south side of

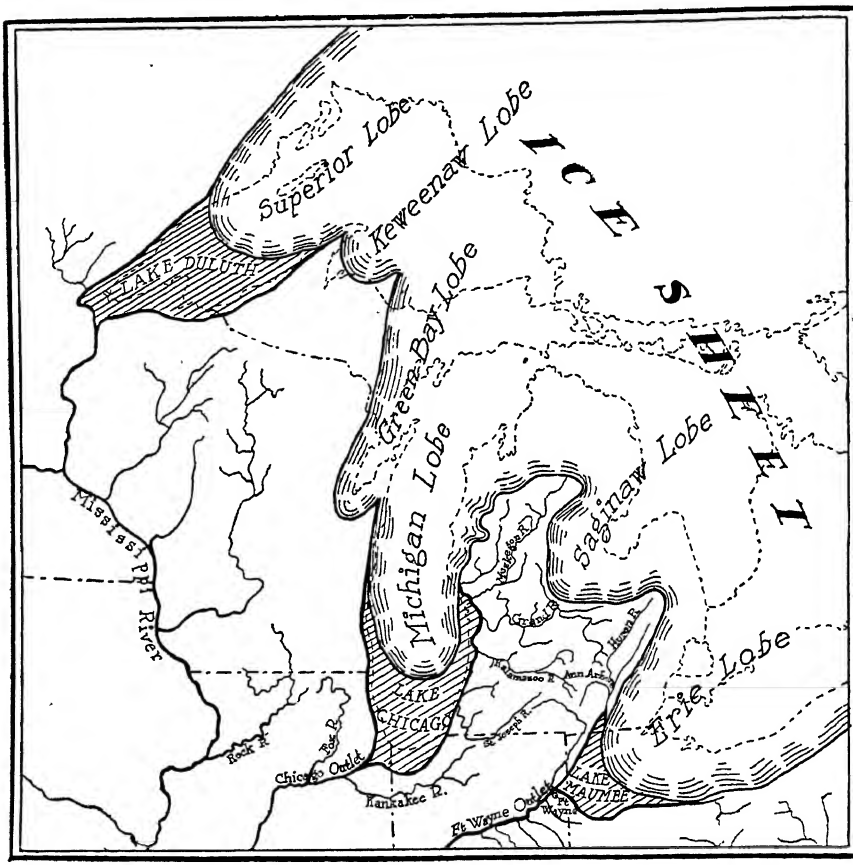


FIG. 516.—The beginnings of the Great Lakes. The ice still occupied the larger parts of the present lake basins. (After Taylor and Leverett, U. S. Geol. Surv.)

the Saginaw ice-lobe, lower than the Fort Wayne outlet. This pass was the Imlay outlet. The escaping waters then skirted the edge of the Saginaw ice-lobe to the valley of the Grand river, following which they crossed the lower peninsula of Michigan, and joined Lake Chicago (Fig. 517), the left horn of which had, by this time, reached thus far north. This constituted the second stage of Lake Maumee.

Somewhat later, the Saginaw ice-lobe retired so that a crescentic lake (Lake Saginaw) gathered about its extremity, and discharged through the Grand River outlet into Lake Chicago, and thence by the Illinois route to the Mississippi. For a time, Lake Maumee continued to discharge by the Imlay outlet into Lake Saginaw, and thence to the Mississippi; but in the course of the retreat, a lower outlet across

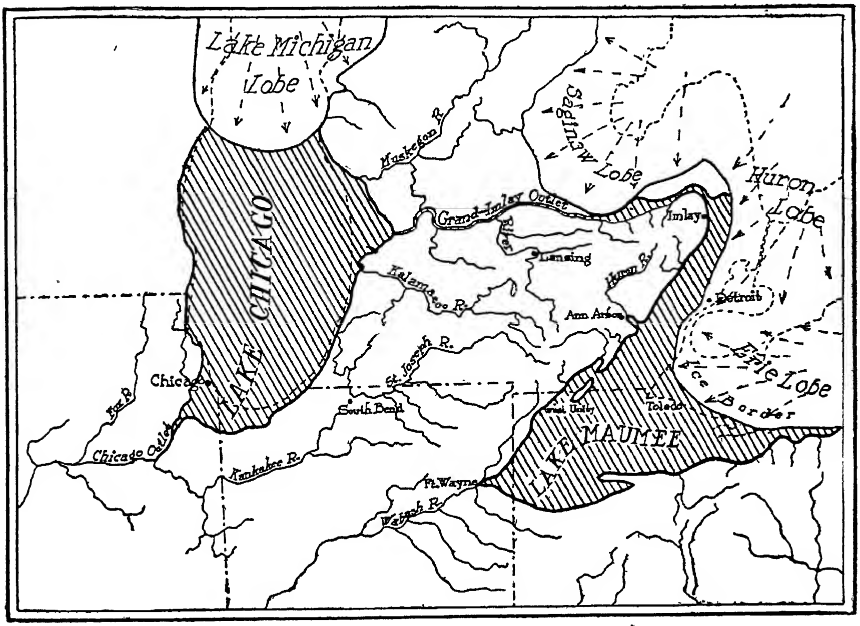


FIG. 517.—A later stage in the development of Lakes Chicago and Maumee. The ice has retreated farther, and the outlet of Lake Maumee has been shifted. (Leverett and Taylor, U. S. Geol. Surv.)

the "thumb" of eastern Michigan was discovered, and the Imlay outlet was abandoned.

Later, the whole Erie basin, and a portion of that of Ontario, became free from ice, and a lake twice the area of the present Lake Erie developed (Lake Arkona), and was marked by its own set of beaches. According to the recent determinations of Taylor, an advance of the ice followed, closing the lower outlet across the Thumb of Michigan, and forcing the water to occupy a higher one at Ubly. This stage was attended by the formation of a beach (the Belmore) at a higher level than the Arkona beaches, which were submerged but not wholly obliterated.

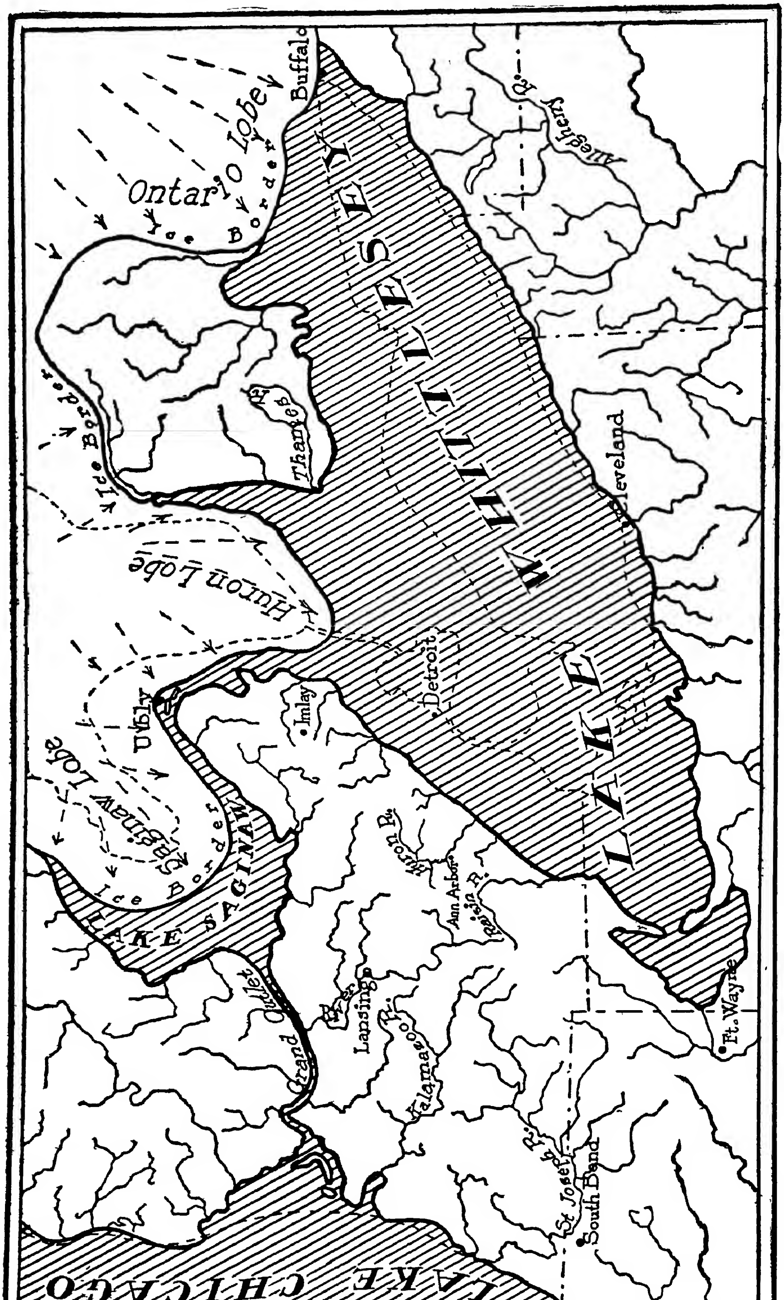


FIG. 518.—A later stage in the development of Lakes Chicago, Maumee, and Saginaw. (Leverett and Taylor, U. S. Geol. Surv.)

The water-body at this stage is known as *Lake Whittlesey* (Fig. 518).

At a still later stage, the Saginaw ice-lobe had retired into the Huron basin, and the ponded waters in the Saginaw basin became confluent with those in the Erie basin, which had, in the meantime, become extended into the borders of the Ontario basin, but were blocked in that direction by the Ontario ice-lobe. The extensive water body thus developed is known as *Lake Warren* (Fig. 519). At first, this lake discharged through the Grand River outlet into Lake Chicago; but later the eastern end appears to have worked its way along the south border of the Ontario ice-lobe into the Finger Lake region of New York, and to have reached at length the Mohawk valley, through which it discharged into the Hudson, thus transferring the sea-connection of the Erie basin from the Mexican Gulf to the Atlantic Ocean. In the course of time, the shape of the water body centering about the Ontario basin was changed as the ice retreated, and the Mohawk outlet was lowered at the same time. Three successive stages of this kind have been named Lake Dana, Lake Lundy, and Lake Iroquois (Fig. 520), respectively, all discharging through the Mohawk.

Meantime, the glacial lakes in the basins of Lake Michigan and Superior experienced analogous shiftings of areas and of outlets. While Lake Iroquois was discharging through the Mohawk valley, Lake Algonquin (Fig. 521), formed by the coalescence of the glacial lakes of the Superior, Michigan, and Huron basins, was discharging its waters eastward. At first the outlet was probably by the St. Clair-Erie route, through Lake Iroquois, to the Mohawk; but later, when the ice had retired farther north, an outlet appears to have been effected from Georgian bay, via the Trent river to Lake Iroquois (Fig. 521). This lower outlet to the north was probably due to a depressed condition of the area to the northeast, due to the weight of the ice mass and the attraction of the latter on the water adjacent to it.

When at length the Ontario ice withdrew from the Adirondacks so far as to permit the ponded waters to find an outlet lower than that by way of the Mohawk, between the ice and the north base of the mountains, a new series of lowerings of the ponded water-body followed. At first the outlet seems to have skirted the Adirondacks and emptied into a glacially ponded water-body (glacial Lake Champlain) that occupied the Champlain basin, and discharged southward into the Hudson.

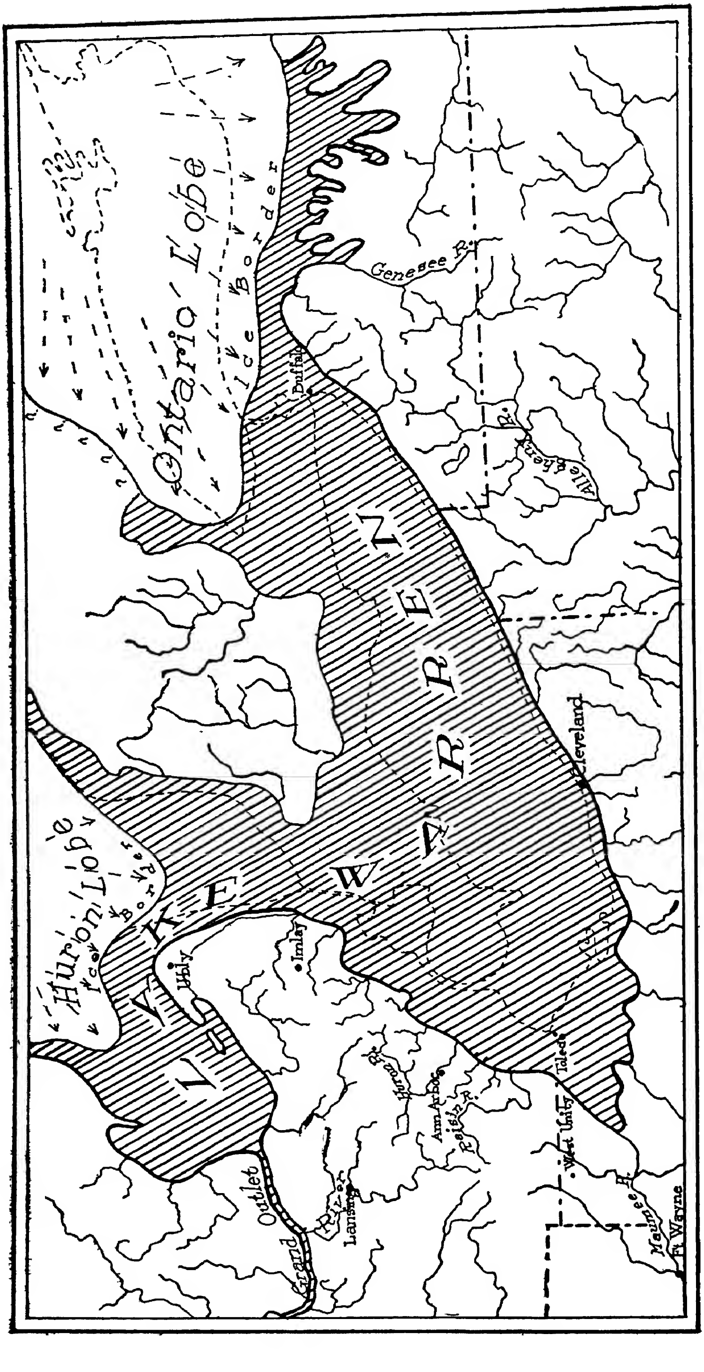


FIG. 519.—Illustrating the relations of standing water to the ice in the Erie and Ontario regions after the ice had retreated farther than represented in Fig. 518. The numerous lobate lakes south of the Ontario lobe of ice will be noted, and also the fact that the discharge of Lake Warren was still to Lake Chicago. (Taylor and Leverett, U. S. Geol. Surv.)

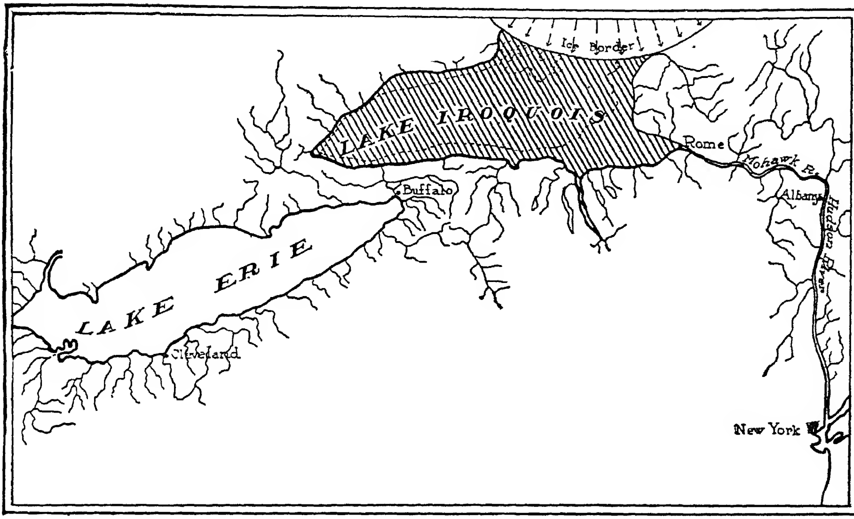


FIG. 520.—Lake Erie and Lake Iroquois; a stage in the history of the eastern Great Lakes, after the ice had retreated so as to open the Mohawk outlet. (Gilbert, U. S. Geol. Surv.)

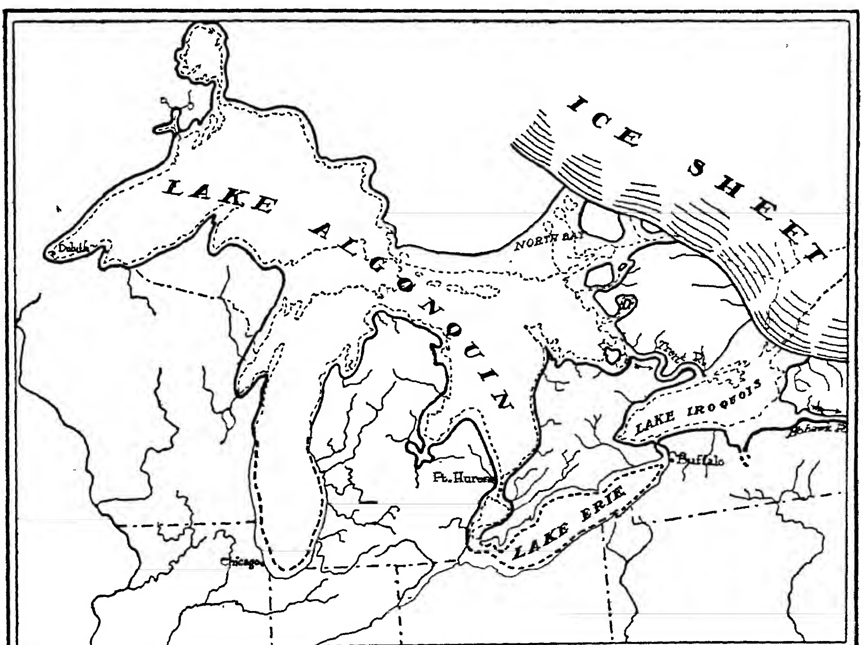


FIG. 521.—The Great Lakes at the Algonquin-Iroquois stage. (After Taylor.)

With further stages of ice retreat, the outlet was let down to the Champlain arm of the sea presently to be noted. By this time Lake Algonquin had given place to the great Nipissing Lakes (Fig. 522), which had their outlet via Lake Nipissing to the Ottawa, and thence to the Champlain arm of the sea. Subsequently the outlet was shifted to its present position, probably by gentle warpings of the surface.[1]

Without doubt similar complicated lake histories attended the retreat of the ice in the Mackenzie and Hudson Bay basins, but little is yet known regarding them.

A very important lake was also formed in the Red River valley of the north (Lake Agassiz), discharging in its earlier history, into the Minnesota river at Lake Traverse. As Lake Agassiz was not connected with the complex system of basins of the St. Lawrence valley, it had a comparatively simple history. It grew to the northward with the retreat of the ice which held it in at that end, and continued to discharge into the Minnesota river at Lake Traverse, cutting down its outlet and forming a series of beaches about its borders, until the retreat of the ice enabled it to find a northerly outlet in some position yet unknown. While discharging by this northerly outlet, it made another set of beaches. On the further withdrawal of the ice, its waters were discharged, and the lake became extinct. Lakes Winnipeg and Winnipegosis may be regarded as its diminutive successors in a sense, but they are rock-bound or earth-bound lakes, while Lake Agassiz was ice bound on its northerly border.[2] Multitudes of smaller lakes came into existence in the regions of strong relief as the ice withdrew. Their histories are for the most part less complicated. Few of them have been studied in detail.

It is probable that there were corresponding lacustrine sub-stages at the close of each of the several glacial epochs, but their history has not been worked out, and because of the overriding of later ice, will probably never be deciphered in detail.

The evidence which demonstrates the existence of these expanded lakes is found chiefly in the deposits which they made, and in the topographic features which they developed about their shores. Many of the former shore-lines have been traced in detail, and most of them

[1] An account of the history of the Great Lakes, by F. B. Taylor, is found in Studies in Indiana Geography.

[2] The glacial Lake Agassiz, Upham, Mono. XXV, U. S. Geol. Survey, 1895.

depart notably from horizontality. Those of different stages of the lakes frequently depart unequally from a common plane. In general, they rise to the north and northeast.

XIII. **The Champlain sub-stage.**—The significant feature of this stage is represented in Fig. 522, which represents an arm of the sea extending up the St. Lawrence to Lake Ontario, filling the basin of Lake Champlain, and probably connecting southward by a narrow strait along the site of the Hudson valley with the ocean.[1] The sediments deposited in this arm of the sea contain shells and bones of marine animals. The marine fossils are found at various places about Lake Champlain at altitudes varying from 400 feet or less about the south end of the lake, to 500 feet at the north end, and about 600 feet near the east end of Lake Ontario.[2]

The most distinctive deposit made in this Champlain arm of the sea is laminated clay, the material for which was partially supplied by drainage from the ice to the north. While the "Champlain clays" are the best-known phase of the deposits of this stage, sand and gravel were deposited contemporaneously in appropriate situations. The clays of the Hudson valley are extensively used for brick. Similar clays occur in the Connecticut and some other New England valleys, and in the valley west of the Palisade ridge. In all cases, the clays rise notably to the northward and serve as a rough measure of the post-glacial change of altitude of the land.[3]

At about the same time the sea stood higher than now relative to the land on the coast of Maine, where marine shells, including species of *Myá, Astarte, Leda,* and *Yoldia,* among many others, occur up to elevations of 200 feet or more.[4] Marine fossils of post-glacial age occur up to elevations of about 600 feet above James Bay,[5] and other marks

[1] Peet, Jour. of Geol., Vol. XII (1904), pp. 415–469, 617–661; Salisbury, Glacial Geol. of N. J., pp. 196–200.

[2] Dawson, G. M. Am. Jour. Sci., 3d ser., Vol. VIII (1874), p. 143; Dawson, J. W The Canadian Ice Age, p. 201, and Am Jour. Sci., Vol. CXXV, 1883.

[3] Other papers touching the Champlain are the following: Reis and Merrill, 10th Ann Rept. N. Y. State Geologist, 1890; Reis, Bull. N Y. State Mus., Vol. III, 1895; Baldwin, Ann. Geol., Vol XIII, 1894; Davis, Proc. Bos Soc. Nat. Hist., Vol. XXV, 1891; Upham, Bull. Geol. Soc. Am., Vol. III, 1891; Kellogg, Science, Vol. XIX, 1892; and Woodworth, Bull 84 N. Y. State Mus

[4] Dana, Manual of Geology, 4th ed, p. 982; and Stone, Jour. of Geol., Vol. I, pp. 246–254

[5] Bell, Am. Jour. Sci, 4th ser., Vol. I, pp 219–228, 1896.

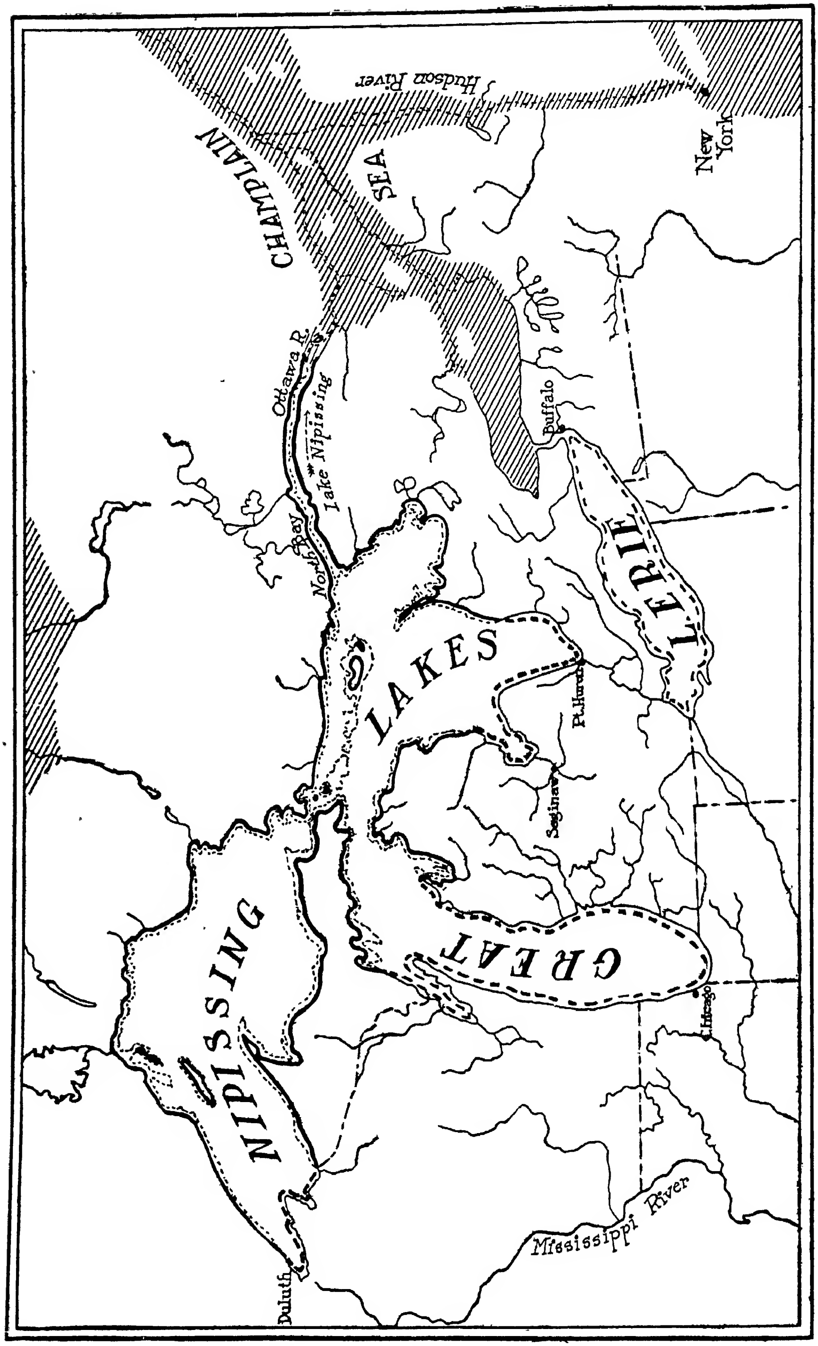


FIG. 522.—A stage later than that represented in Fig. 520. The shaded area represents the tract which is thought to have been covered by sea-water. (After Taylor.)

of post-glacial submergence are reported at still greater heights in Labrador.

The Loess.

The term loess is used with not a little latitude, both as a textural and a formational name. Lithologically, loess is a variety of silt intermediate between the finest sand and clay. In general, it is free from stones of all sorts, except the concretions which have been developed in it since its deposition. In the exceptional cases where stones occur in it, they are confined to its extreme basal portion. At its base, too, it is sometimes interstratified with sand, especially where it is thick.

The composition[1] of the loess is significant in that it contains angular, undecomposed particles of the commoner carbonates, calcite and dolomite, and silicates, such as the feldspars, the amphiboles, the micas, etc. Even the rarer silicates, such as epidote, apatite, tourmaline, zircon, etc., have been identified. Magnetite also is a common, though never an abundant, constituent. These constituents strongly suggest that the material of the loess was derived from the flour of the glacial mill. In color it is predominantly buffish brown, but in not a few places it has a bluish cast a few feet below the surface.

By virtue of its peculiar mode of adhesion and of its porosity, the loess often stands with vertical faces (Fig. 523) for long periods, where sand or clay would be degraded into slopes. Roads on the loess tend to assume the form of miniature box canyons, because the loess of the road-bed is washed or blown away, while that on either side stands up with steep or even vertical slopes. Its porosity seems to be due in part to the size, shape, and arrangement of its grains, and in part to vertical tubelets that usually affect it, and which are supposed to have been caused by rootlets. Weathered faces of the loess often show a rude columnar structure (Fig. 524), the columns being one to several feet in diameter. The loess often shows no stratification, but in its coarser phases there is often some suggestion of such structure, and when the loess proper is interbedded with sand, this suggestion becomes distinct.

The best known portions of the loess in America and Europe are associated with glacial formations, though the loess extends far beyond

[1] Sixth Ann. Rept. U. S. Geol. Surv., pp. 244 et seq.

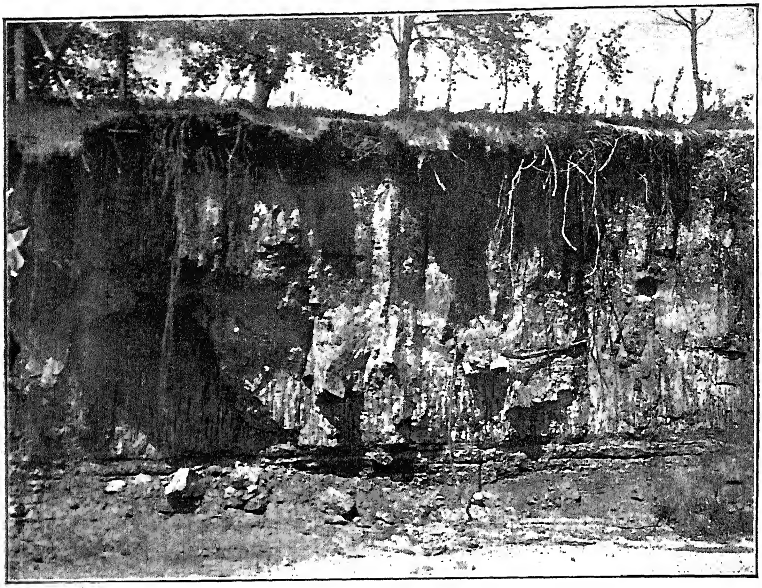


FIG. 523.—A section of loess in Iowa, showing its ability to stand with vertical or even overhanging faces. (Calvin.)

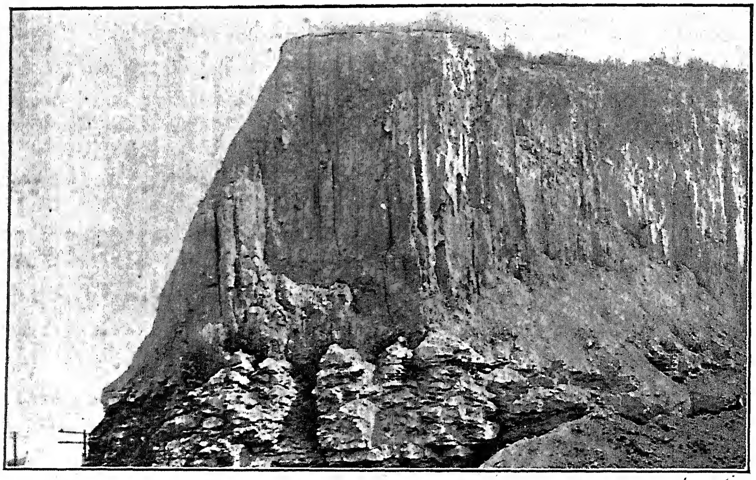


FIG. 524.—A section of the loess at Kansas City, showing its rude columnar structure, (Mo. Geol. Surv.)

the borders of the drift in some directions, in both continents, and in America it occurs in the driftless area (Fig. 470). In Turkestan, Mongolia, and China,[1] where loess has its greatest known development, it is not known to be immediately associated with glacial formations, though its age is probably about the same as that of the chief deposits in Europe and America.

In North America, the loess does not occur east of the Mississippi basin, and has no great development east of the Wabash river. The greatest development is in Illinois, Iowa, Nebraska, and the States lying south of them, even beyond the reach of the most extensive ice-sheet. Within this area, its distribution is peculiar in that (1) it is thick about the border of the area occupied by the Iowan ice-sheet; (2) it thins out on the inter-stream areas as it is traced away from this border tract; while (3) it retains its thickness along the valleys, especially the larger ones, but thins gradually from them. Especially does it follow the main streams that lead away from the Iowan drift-sheet. It follows the Mississippi nearly to the Gulf, and is especially thick along this stream and the Missouri. Its habit is to occupy the bluffs immediately overlooking the valleys, and it was formerly known as the *Bluff formation* on this account. In this position, it has more than its average thickness and coarseness of grain, and grows thinner and finer in grain back from the river bluffs until it is lost in a vanishing edge, while its material, at the same time, loses its distinctive characteristics.

In the regions next south of the borders of the Iowan and Wisconsin drift-sheets, it mantles the divides between the main streams; but farther south it is more confined to the valley borders. Within the general area of its occurrence it has little regard for topography. It can indeed hardly be said to have an upper limit. This independence of topography is one of its significant features. Within the drift-covered part of the Mississippi basin, the loess occurs (1) as a mantle overlying the drift (Fig. 525), and (2) between sheets of drift. Its relations to the drift-sheets make it clear that it was accumulated at several different stages of the glacial period, but within the glaciated area the accumulation at one of these stages far exceeds

[1] Von Richthofen, China. This author early (1877) advocated the eolian origin of the loess of China, but this explanation has not passed unchallenged. See Skertchley and Kingsmill, Q. J. G. S., Vol.LI, 1895, pp. 238–254.

that at all others, both in volume and areal extent. The loess deposited at this stage is often referred to as "the loess," and is usually correlated in time with the Iowan drift, though the strict accuracy of this correlation has been questioned. It is at least later than the Kansan and Illinoian sheets of drift which it mantles, and earlier than the Early Wisconsin which overlies it. Locally, a thin mantle of loess overlies the older part of the Early Wisconsin drift, and, more rarely

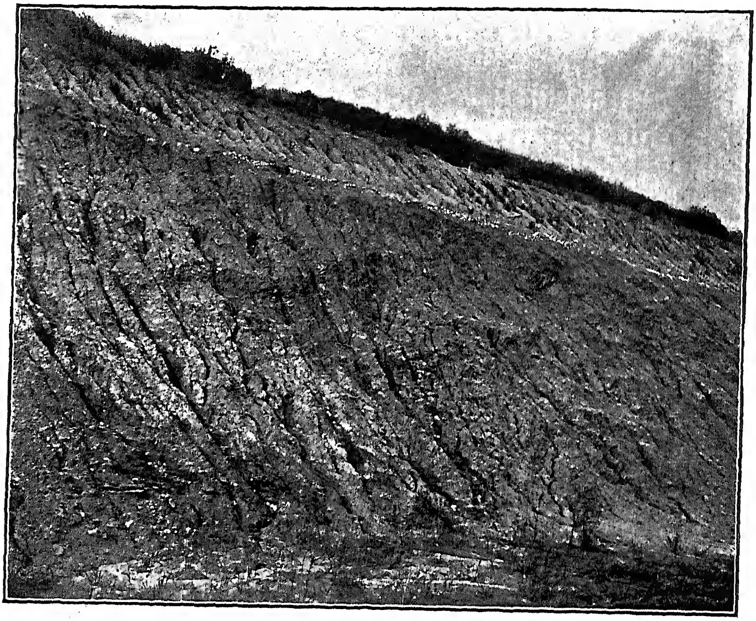


FIG. 525—Loess overlying Kansan drift, with a thin band of pebbles at the junction; Iowa. (Calvin.)

the younger. It even overlies the Late Wisconsin drift in places, though the Wisconsin drift-sheets are usually free from it.[1] Loess does not appear in quantity between the Illinoian and Kansan formations, nor between the Kansan and sub-Aftonian.

Outside the drift there are often two distinct sheets of loess. They are sometimes separated by a well developed soil zone, beneath which the surface of the lower loess shows the effects of prolonged weathering and oxidation.[2]

[1] Jour. of Geol., Vol. IV, pp. 929–937.
[2] Report on Crowley's Ridge, Ark. Geol. Sur., pp. 224–235.

On portions of the Great Plains, and in some of the basins of the Western mountain regions, there are deposits called loess, some of which are closely similar to the loess of the drift region, while others are quite different. But there is nowhere a development at all comparable to that on the borders of the plateaus of Asia, particularly in China. In Washington and Oregon, material which in its general character is quite similar to the loess of the Mississippi basin is widespread.[1]

The loess of the Mississippi basin rarely attains a thickness of more than a score or two of feet, and this only along main streams; but exceptionally its thickness approaches 100 feet. Thicknesses of 10 feet are much more common than greater ones.

The loess contains characteristic accessories of two classes, namely, concretions and fossils. The concretions are of lime carbonate and iron oxide. The former are often irregular and of such shapes as to have received the appellation of "petrified potatoes." Concretions of the sort to which this name is applied are usually though not always hollow. The concretions of lime carbonate are often of other shapes, for example, cylindrical. The ferruginous concretions take various forms, one of which is the "pipe stem," perhaps formed about rootlets.

The fossils of the loess are chiefly gastropods (Fig. 526). They were originally reported to include both terrestrial and aquatic forms, and this has much influenced opinion with reference to the origin of the formation. According to Shimek, however, the shells in the upland loess are almost exclusively those of land species, or such as frequent isolated ponds.[2] He finds a practical absence of those that frequent rivers and lakes. There is, however, a lowland silt formation, classed by some as loess, called by others loess-loam, in which fresh-water fossils are found. The other fossils are bones and teeth of land mammals.

Origin.—The origin of the loess has long been a standing puzzle, and opinion is still divided between an aqueous and an eolian origin, with a growing tendency toward the latter. Some geologists divide the honors between the two hypotheses. There is little doubt that the loess-like silt deposits which occur in the terraces of rivers are

[1] Jour. of Geol., Vol. IX, p. 730.

[2] Ibid., Vol. IV, pp. 929–937, and Loess Papers, Bull. Labr. Nat. Hist., Univ. Iowa, 1904.

of fluvial origin; but some investigators, while assenting to this conclusion, would exclude such deposits from the loess proper. Some, indeed, would so define the loess as to make it an eolian product. The distribution of the loess along the rivers naturally suggests a genetic

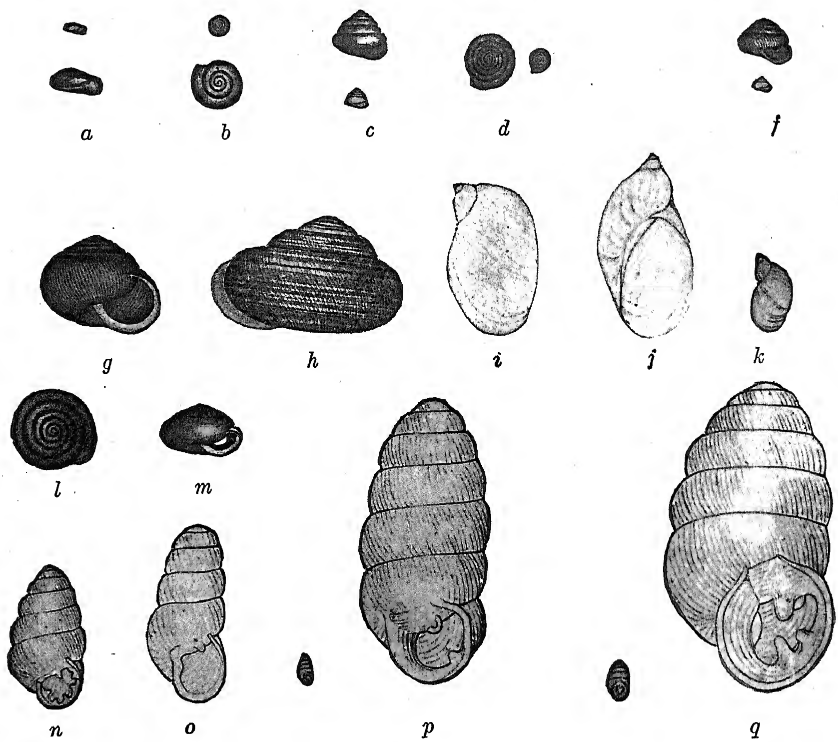


FIG. 526.—Loess Shells. *a–b*, *Zonitoides minusculus* (Binney); *c–d*, *Euconulus fulvus* (Drap.); *–f*, *Strobilops labyrinthica* (Say); *g*, *Polygyra clausa* (Say); *h*, *P. multilineata* (Say); *i–j*, *Succinea obliqua* Say; *k*, *S. avara* Say; *l–m*, *Polygyra monodon* (Rack); *n*, *Bifidaria pentodon* (Say); *o*, *B. corticaria* (Say); *p*, *B. muscorum* (Linn.); *q*, *B. armifera* (Say). The small figures adjacent to some of the large ones show the natural size of the shells.

relation to them. This is conceded, without proving that the loess is fluvial.

By the aqueous hypothesis, the loess is assigned to direct deposition by the rivers, or their lake-like expansions. To make this possible, it is necessary to suppose that the waters stood at elevations 200 to 600 feet higher than now, relative to adjacent surfaces. This involves difficulties that have never been satisfactorily met, for great areas

which should have been covered by water according to this hypothesis, have no loess. Thus the loess occupies the bluffs on the east side of the Mississippi river, down to the highlands of the southwestern part of Mississippi, where it mantles surfaces which lie 300 or 400 feet above the present river, and overlook the lowlands of Louisiana, where there is no loess. Between the bluffs and the lowlands, there is no restraining barrier, and no shore-line, or other topographic features that should have been left by an estuary, had the depositing waters assumed that form. Furthermore, if the waters of rivers or their lake-like expansions were high enough to cover the areas overspread by loess, it is not clear that there could have been an appropriate habitat for the abundant land fauna of the time.

Under the eolian hypothesis, or at least one phase of it, the river flats are supposed to have supplied the material of the loess, which was whipped up by the winds and re-deposited on the adjacent uplands, perhaps being held, after deposition, by vegetation. The rivers are thus made essential factors in the distribution, though not the direct agents of deposition. The preponderance of loess on the east sides of some main rivers is attributed to the prevailing westerly winds. This hypothesis seems on the whole to best fit the phenomena of at least a large part of the loess of the Mississippi basin. The constituents of the loess, which appear to have come from the glacial grinding, were derived either directly from the deposits made by glacial waters, or from the secondary erosion of the glacial formations. It is probable, too, that the derivation of loess silt from glacial drift directly, before it became clothed with vegetation, and without the intervention of rivers, should be recognized.[1]

[1] *References.*—Loess is described in the geological reports of the following States: Iowa, Vols. III, IV, V, VII, VIII, IX, X, XI, XII, XIII, and XIV (Calvin, Bain, Shimek, and others); Illinois, Vols. V and VI (Shaw and Worthen); Missouri, Reports of 1855–71, 1872, and 1873–4, and Vols. IX and XII (Pumpelly, Broadhead, Marbut. Todd, Winslow); Arkansas, Report on Crowley's Ridge; Kentucky, Report on Jackson Purchase Region (Loughridge); Tennessee, Geology of Tennessee, and Resources of Tennessee (Safford); Louisiana, Reports of 1899 and 1902 (Harris and Veatch); Mississippi, Reports of 1854 and 1860 (Hilgard); Minnesota, Vol. I, and Report for 1880, (Winchell, Upham); South Dakota, Bull. I (Todd), and Nebraska, Vol. I (Barbour). Other references are, Pumpelly, Am. Jour. Sci., Vol. XVII, 1879; McGee and Call, idem., Vol XXIV, 1882; McGee, Eleventh Ann. Rept. U. S. Geol. Surv.; Chamberlin and Salisbury, Sixth Ann. Rept. U S. Geol. Surv.; Russell, Geol. Mag., Vol. VI, 1889; Todd, Am. Assoc. Adv. Sci., Vol. XXVII, 1987,

The fact that the chief loess formation of the drift region is related, in the way above described, to the area of the Iowan drift, has led to the conception that at the time of the Iowan ice invasion, the glacial streams were more sluggish and widely wandering than in most other stages, and that by fluctuations between flood and recession, and by shiftings, they exposed more extensive silty flats, while at the same time the climate was more arid, the silt flats more quickly dried, and the dust more freely picked up by the winds and distributed over the adjacent uplands. It is a singular fact that the outwash from the ice edge during the Iowan and at some other stages, has left little record of itself, unless the loess be its record. Gravel trains of moment have not been found. The loess deposits seem to be, in some way, related to these stages, and both phenomena, perhaps, imply aridity, strange as that may seem in a glacial epoch.

Opposed to the idea of a strict correlation with an ice stage, Shimek has urged that the mollusks whose shells are the chief fossils of the loess are such as inhabit the region to-day, and do not indicate, by pauperate forms or otherwise, such climatic conditions as might naturally be assigned to the near presence of an ice-sheet. A notable dwarfing of the fossil species in the loess had previously been announced, and regarded as an evidence of rigorous climate. Shimek suggests the interglacial accumulation of the loess, and a careful test of this hypothesis is merited. It is consistent with the fact that there is often an aggregation of stones, pebbles, etc., on the surface of the till, below the loess (Fig. 525). The concentration of stony matter here has been interpreted as the result of surface wash, after the deposition of the till below, and before that of the loess above.

The deposits in the West called loess seem to be in part fluvial and in part eolian.

Bull. Phil. Soc. of Wash., Vol. IV., Bull. Geol Soc. of Am., Vol. V, Science, New Ser., Vol. V; Shimek, Am. Geol., Vols. XXVIII and XXX, Bull. Ia. Lab. Nat. Hist., Vols. I, II, and V, Proc. Ia. Acad. Sci., Vols. III, V, VI, and VII; Leverett, Am. Geol., Vol. XXXIII, and Mono. XXXVIII; Calvin, Bull. Geol Soc. Am., Vol. X, p. 119; Chamberlin, Jour. of Geol., Vol. V, 1897; Hershey, Am. Geol., Vols. XII and XXV, 1900; Fuller and others, Patoka and Ditney, Ind., Folios, U. S. Geol. Surv.; Davis, Explorations in Turkestan, 1905

The Duration of the Glacial Period.

The desire to measure the great events of geological history in terms of years increases as the events approach our own period and more intimately affect human affairs. The difficulties attending such attempts are, however, formidable, and the results have an uncertain value. At best they do little more than indicate the order of magnitude of the periods involved. Geological processes are very complex, and each of the coöperating factors is subject to variations, and such a combination of uncertain variables introduces a wide range of uncertainty into the results.

Efforts to determine the date and duration of the glacial period fall mainly into two categories: (1) efforts to estimate the relative duration of the several glacial and interglacial epochs, and (2) efforts to measure in years the interval since the close of the glacial period.

(1) The best data for estimating the relative duration of the several glacial stages are found in the region bordering the Mississippi river, for it is there only that all members of the series are present. There only also do they come into such relations with one another as to furnish fair facilities for comparison. The criteria that have been used in estimating relative duration embrace (1) the surface erosion and the cutting of special gorges, (2) the depths of leaching and weathering, (3) the internal changes, (4) the decomposition of the pebbles and bowlders, (5) the amount of vegetable growth in interglacial intervals, (6) the climatic changes indicated by floras and faunas, (7) the times needful for the migration of faunas and floras, particularly certain plants whose means of migration are very limited, (8) the times necessarily required for advances and retreats of the ice. and similar means. A few of these are subject to direct measurement, as the relative amounts of erosion; but for the greater part they are matters of judgment, in which the value of the result is much affected by the personal equation.

A collation of the judgment of five of the glacial geologists who have most studied the data in their most favorable expressions is the basis for the estimates embodied in the following table. In this case, the time-datum for each sheet of till is the stage at which it began to suffer erosion, which, of course, would be slightly after the beginning

of the ice retreat. The time-unit is the period which has elapsed since the Late Wisconsin began to be exposed to erosion:

From the Late Wisconsin to the present.	1	time-unit.
From the Early Wisconsin to the present.	2 to 2½	time-units
From the Iowan to the present.	3 to 5	"
From the Illinoian to the present.	7 to 9	"
From the Kansan to the present.	15 to 17[1]	"
From the sub-Aftonian to the present.	x	"

So far as now known, the sub-Aftonian is everywhere buried by later deposits, and the method of estimate by erosion is inapplicable to it. Some hints of its relative age may be gained from the growth of vegetation, and the development of the fauna and flora between it and the Kansan, and from the superior amount of disintegration and other internal changes which its material suffered; all of which imply a considerable period anterior to the Kansan. If the sub-Aftonian is equivalent to the very old drift of New Jersey and Pennsylvania (the Jerseyan), the erosion measure may be applied there, with the result of indicating great antiquity.

The average of these estimates is not far from the geometrical series 1, 2, 4, 8, 16. This symmetry is not presumed to have any dynamic significance, but it may serve a mnemonic purpose. Subsequent studies have tended rather to increase than diminish the high ratio of the earlier epochs. In particular, the studies of Calvin in southwestern Iowa have strongly impressed him with the relative greatness of the erosion of that region. It is not unlikely, however, that this was in some measure dependent upon a more favorable topographic attitude, due to a relatively greater westward slope before the western side of the Great Plains was lifted to its present elevation.[2]

Under full admonition as to the tentative nature of such estimates, the figures above given may perhaps be taken as representative. There is every presumption that they will need to be modified by further researches, probably in the direction of extension.

[1] A special estimate of the amount of the erosion suffered by the Kansan and Late Wisconsin, respectively, in central Iowa, where they lie side by side under conditions favorable for the comparison, gave Bain a ratio of 17 to 1. Geology of Polk County, Iowa Geol. Surv , Vol. VI.

[2] For estimates of period of time involved in certain glacial oscillations, see Taylor, Jour. of Geol., Vol V, 1897.

(2) Of the efforts that have been made to measure in years the post-glacial interval, those based upon the recession of Niagara and St. Anthony Falls are the most important, and are all that can be considered here.[1] It is important, however, to note precisely what is being measured. In both these instances, the measurement attempted is the time occupied in the recession of the falls from the point of their initiation to their present positions. It is as important to know *when they began* their gorge cutting, as to know how long they have been occupied in it. The gorge-cutting of the Niagara Falls could not have begun until the Mohawk outlet of the ice-ponded lakes, previously sketched, was abandoned, because the escarpment through which the cutting subsequently took place was still submerged while the lake discharged through the Mohawk valley. The time measured by the Niagara cutting was only that which has elapsed since the ice-border retired from the northeast flank of the Adirondacks sufficiently far to permit the waters of the ancestral Lake Ontario to find an outlet lower than the Niagara escarpment, and no very effective cutting could take place until the waters were withdrawn to something near their present level.

If the border of the ice-sheet at this stage (Fig. 522) is compared with the border of the ice at the maximum Late Wisconsin stage (Fig. 470), it will be seen that a retreat of the ice-border, measured along the axes of the more protrusive lobes, of some 600 miles had taken place. In the course of this retreat, about a score of morainic ridges had been formed. Some of these appear to have represented

[1] *References on Niagara:* Pohlman, Am. Assoc Adv. Sci., Vol. XXXII, 1883, and Vol. XXXV, 1887; Science, Vol. II, 1883, and Vol. VIII, 1886; Trans. Am Inst. Min. Eng., Vol. XVII, 1889, and Eng and Min. Jour., Vol. XLVI, 1888. Wright, Am. Jour. Sci , 3d ser., Vol. XXVIII, 1884; Sci. Vol. V, 1885; Bibliotheca Sacra, 1884 Proc Am. Assoc. Adv. Sci , Vol. XLVII, Science, new ser., Vol. VIII; Am. Geol., Vol XXII, 1898; Pop Sci. Mo., Vol. LV, 1899, and Am Jour. Sci , 3d ser , Vol. XXVIII. Gilbert, Am. Jour. Sci., 3d ser., Vol. XXXII, 1886; Science, Vol. VIII, 1886; Proc. Am. Assoc. Adv. Sci , Vol. XXXV, 1887; Rept. N. Y. Com. State Res. at Niagara, 6th Rept. 1890, and Chapter in Physiography of the United States. Upham, Am. Jour. Sci., 3d ser., Vol. XLV; Jour. Geol., Vol. I, 1893; Am. Geol., Vol. XI, 1893, and XVIII, 1896, and Pop. Sci. Mo , Vol. XLIX, 1896. Spencer, Am Jour. Sci., 3d ser., Vol. XLVIII, 1894, and Am. Geol., Vol. XIV, 1894; and Taylor, Bull. Geol. Soc. Am., Vol. IX, p. 84.

St. Anthony Falls: Winchell, N. H. Fifth Ann. Rept. Natl. Hist. and Geol. Surv. of Minn., 1876; Geol. of Minn., Vol. II, 1888, Twenty-third Ann. Rept., 1894; Southall, The Epoch of the Mammoth, p. 373.

appreciable advances, as for example that brought out by the demonstration of Taylor that the Belmore beach of southwestern Michigan was formed by such an advance later than the Arkona beaches that stand below it. Phenomena connected with the moraines themselves imply advances in other cases. It cannot therefore be assumed consistently that the retreat of the ice from its maximum Late Wisconsin advance to its position at the time the Niagara gorge began to be cut, was a rapid, uninterrupted one. Rather must it be assumed that the agencies that made for advance closely matched, and occasionally over-matched, the agencies that made for retreat.

Before attempting to place a value upon the period so represented, the time at which the gorge below St. Anthony Falls began to be cut may well be considered also. From the normal methods of the glacial streams of retiring ice-sheets, it is to be presumed that for a time subsequent to the retreat of the ice-edge from the present location of St. Anthony Falls, at Minneapolis, the outwash trains of the region were being deposited, for the waters issuing from the edge of the ice, so long as it lay on the southern slope, must apparently be presumed to have been overburdened with glacial detritus which they were throwing down along the courses of their channels to the southward. Degradation may have taken place locally in the interest of a readjusted gradient, but the general phenomenon must apparently have been aggradation. This should have continued until the ice passed beyond the northerly water-shed, or until the glacial waters, through the agency of large lakes, were freed of their detritus. In direct support of this conception is the abundant evidence that the Mississippi trench, as far down as the mouth of the Chippewa river, was filled with glacial detritus to heights ranging from 100 to 120 feet or more above the present river surface. Below the mouth of the Chippewa, the glacial filling appears to have declined gradually to heights of 80, 70, 60, and 50 feet above the river, the last in the latitude of central Illinois. Beyond this, satisfactory tracing of the terrace remnants has not yet been made, but in the Mississippi valley below, there is a persistent series of terraces ranging from 40 to 60 feet above the present river, which have been tentatively regarded as the probable southern representatives of this stage of aggradation. As far down as Natchez, these terraces are fully 50 feet in height, which seems to imply that the glacial filling reached a graded condition about the middle latitude of

Illinois, and thence to the Gulf took on a gradient comparable to that of the existing flood-plain of the Mississippi.

When therefore the glacial aggradation ceased, it was first necessary to clear out the Mississippi trench and lower the river before effective cutting of the gorge below St. Anthony Falls could begin. The waters of Lake Agassiz appear to have been an effective factor in this clearing out, for, on account of the extent of the lake, the detritus of the streams emptying into it from the ice was effectually deposited, and the waters issuing from the lake were clear and capable of taking up and rolling on the gravel and sand that filled the great trench. It would appear from the configuration of the Minnesota valley, that by the time Lake Agassiz ceased to discharge through the Minnesota River, the filling of that river and of the upper Mississippi had been cleared away to such a depth as to give the upper Mississippi an effective fall for cutting the gorge below St. Anthony Falls. Perhaps the cutting might have been gradually initiated somewhat before, but the time-rate of the recent falls could not be properly applied to it until after the full height of the fall was attained. The position of the ice-border at the stage at which Lake Agassiz ceased to flow through the Minnesota river is not yet known, but it had retreated far enough to permit the lake waters to escape by some northerly route. Under any probable hypothesis, this implies a retreat of the ice-edge some 700 to 800 miles from its extreme extension at Des Moines, a distance appreciably greater than that requisite for initiating the Niagara gorge-cutting.

Glacialists vary much in their estimates of the average rate of retreat of the ice-border under such conditions. This retreat is of course not measured by the rate of melting of the ice alone, but by *the difference* between the rate of melting and the rate of advance of the ice, and it is not to be forgotten that the evidence indicates that the latter was at times superior to the former. If, however, to develop a definite conception, and to aid every one in forming his own judgment as to the probabilities of the case, we assume that there were 200 days of effective melting in each year (which each will increase or diminish according to his judgment), and if we allow that the melting was sufficiently superior to the onward movement of the ice to cause the ice-edge to retreat one foot per day (which each again will modify to meet his judgment), and if no advance was made during

the remainder of the year, we have a retreat of 200 feet per annum (to us, an improbably high estimate). The total distance to be covered by the retreat previous to the beginning of the cutting of the Niagara gorge is taken at some 600 miles, or 3,000,000 feet, and the time occupied on the assumption of a retreat of 200 feet per year is 15,000 years, at 300 feet per year, 10,000 years, or at 100 feet per year, 30,000 years. In the opinion of some glacialists even the last represents too rapid a retreat. The same rates applied to the retreat pre-requisite to the St. Anthony recession, give the results 17,000 to 20,000, 12,000 to 13,000, and 35,000 to 40,000 respectively. As already indicated and emphasized, there are no means for a close determination of this factor.

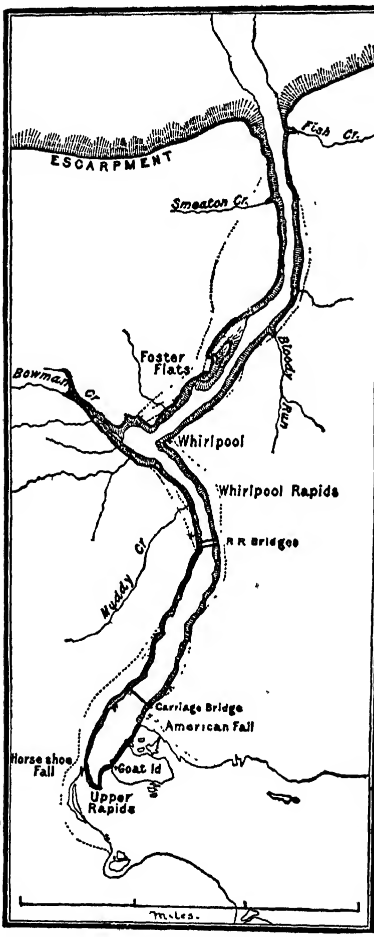


Fig. 527.—The Niagara gorge. The American and the Horseshoe Falls are shown on opposite sides of Goat Island. (After Gilbert.)

If the length of the Niagara gorge be divided by the average rate of retreat since the successive positions of the Falls were located by accurate surveys, the quotient is about 7000. This result is, however, subject to several qualifications which have been well stated by Gilbert and others, but which cannot be discussed in detail here. The chief of these lies in the belief that at the time of the beginning of the cutting of the gorge, the waters of the upper lakes flowed through the Nipissing valley into the Ottawa (Fig. 522), and thence to the sea, leaving only the waters of the Erie basin to pass over the Falls. The belief is also entertained that later, as the land to the north rose relatively, an outlet was found through the Trent river, and that only at a comparatively late date were the waters of the Upper Great Lakes poured

over the Niagara Falls. Now the ordinary rate of erosion is measured by a high power of the volume, when it induces an accelerated velocity (Vol. I, pp. 115 to 123). Precisely how this general law is modified in the case of falls is not known by direct experiment, but it may be inferred from the phenomena of the falls under consideration. Since the Horseshoe and American Falls separated, the latter has retired but slightly from the position it occupied at the time of separation, while the Horseshoe Fall has retired about ten times as far. With little doubt this is due almost wholly to the superior volume of water poured over the latter. This is further indicated by the form of the Horseshoe, since the volume per unit breadth is greater in the center than on the sides. It is also shown by the recent extraordinarily rapid recession at a point where the volume is exceptional.

In view of these considerations, Gilbert, Taylor, and Spencer have urged that the cutting of the narrower portions of the gorge was probably the work of the relatively limited volume of water from the Erie basin, and that the recession proceeded at a relatively slow rate on this account, while the recession has been much accelerated since the upper lakes joined their greater volume to that issuing from Lake Erie. It is this accelerated rate that is used as the divisor in the simple computation that gives 7000 years. In view of the probable rate of increase of recession of the fall, due to increase in the volume of the river after the drainage of the upper lakes was diverted to it, it is thought that the simple quotient 7000 is to be multiplied several times to give the true time-estimate. Spencer places the period at 31,000 or 32,000 years, and Taylor at 50,000 years as an approximate maximum. There are, however, those who do not accept these qualifications and who take appeal to other phenomena that cannot here be discussed. The estimate of Upham, 7000 years, and that of Wright, 10,000 years, are representative of this class. The mean of all the above estimates is about 25,000 years.

From a comparison of the earlier and later surveys of St. Anthony Falls, N. H. Winchell estimates the time of recession from the mouth of the gorge to be about 8000 years. The chief qualification that affects the rate of recession in this case seems to be the rapidity with which the precipitation upon the catchment area above the falls was discharged. This is but another application of the principle involved in the preceding case, for, given a certain amount of precipitation, the rate at

which it is discharged determines its erosive effects. If it is poured rapidly through its outlet, the effects are proportionately much greater than if it be discharged equably throughout the whole season of precipitation. The headwater area of the Mississippi is particularly affected by lakes, ponds, marshes, ill-drained flats, tortuous streams, and other topographic features that even now greatly interfere with the rapidity of discharge of the precipitation of the region. Since the cutting began, the drainage lines have been deepened, widened, and extended in the natural course of things, and the facilities for discharge have been constantly improved. Presumably, therefore, there has been a very appreciable increase in the rate of discharge of the waters since the ice retreated, even without such aid as recent settlement has brought. It follows that the effectiveness of erosion has increased. It is the very latest rate of erosion that was determined and used in the above calculation. The 8000 years should perhaps be increased to 12,000 or 16,000 years.

It will be seen therefore that even in these cases of best data, there are serious sources of qualification, and that these qualifications may, in the judgment of experienced geologists, affect the results to the extent of several hundred per cent. If the range of the estimates of the Niagara be placed at 10,000 to 30,000 years, and if this be added to the range of estimates for the time of retreat of the ice before the falls came into existence, also 10,000 to 30,000, the result is 20,000 to 60,000 years for the time since the Late Wisconsin ice-sheet began to retreat. If the estimates for the St. Anthony gorge-cutting be placed at 8000 to 16,000 years, and the estimates for retreat be added, the range of estimates for the time since the beginning of the Late Wisconsin ice retreat is 20,000 to 56,000 years. These may be taken for a rough, wide-ranging estimate, such as it is, of the time since the climax of the Late Wisconsin ice invasion. Now, using the estimates in the table of relative duration above, and remembering that we are multiplying the errors of the previous estimates, we reach the following dates for the climaxes of the several ice invasions:

Climax of the Late Wisconsin	20,000 to	60,000	years	ago.
" " " Early Wisconsin	40,000 to	150,000	"	"
" " " Iowan	60,000 to	300,000	"	"
" " " Illinoian	140,000 to	540,000	"	"
" " " Kansan	300,000 to	1,020,000	"	"
" " " Sub-Aftonian	y to	z	"	"

We place very little value on estimates of this kind, except as means for developing a concrete sense of proportion.

Foreign.

In Europe, the succession of ice epochs and formations is not less complex than in North America. The following table gives the classification of Geikie:[1]

XI.	Upper Turbarian	= Sixth Glacial Period.
X.	Upper Forestian	= Fifth Interglacial Period.
IX.	Lower Turbarian	= Fifth Glacial Epoch.
VIII.	Lower Forestian	= Fourth Interglacial Epoch.
VII.	Mecklenburgian	= Fourth Glacial Epoch.
VI.	Neudeckian	= Third Interglacial Epoch.
V.	Polandian	= Third Glacial Epoch.
IV.	Helvetian	= Second Interglacial Epoch.
III.	Saxonian	= Second Glacial Epoch.
II.	Norfolkian	= First Interglacial Epoch.
I.	Scanian	= First Glacial Epoch.

These several stages cannot now be correlated with confidence with those of North America. According to Geikie's interpretation, the ice of the Scanian epoch (perhaps = Jerseyan) was less extensive than that of the next epoch, and its deposits have been definitely recognized in but few places. In the Norfolkian (Aftonian?) epoch, Great Britain is thought to have been joined to the continent and to have enjoyed a climate as mild as that of the present time. In the Saxonian (Kansan?) epoch, the ice attained its maximum development and covered the area shown in Fig. 528. In the deposits of the interglacial Helvetian epoch, fossils denoting both cool and warm climates are found, though perhaps not at the same horizon. The central European flora of this stage indicates a climate milder than the present. In the Polandian epoch, the ice-sheet was less extensive than in the Saxonian, and the direction of ice movement was at variance with that of the earlier epoch in many places. The deposits of the Neudeckian interglacial epoch are partly marine and partly non-marine, and the faunas

[1] Jour. of Geol., Vol. III, pp. 241–269.

are temperate, or at least not arctic. The ice of the Mecklenburgian (Early Wisconsin?) stage developed the stout moraines of North Germany. At this time the ice-sheet of Scandinavia was not continuous

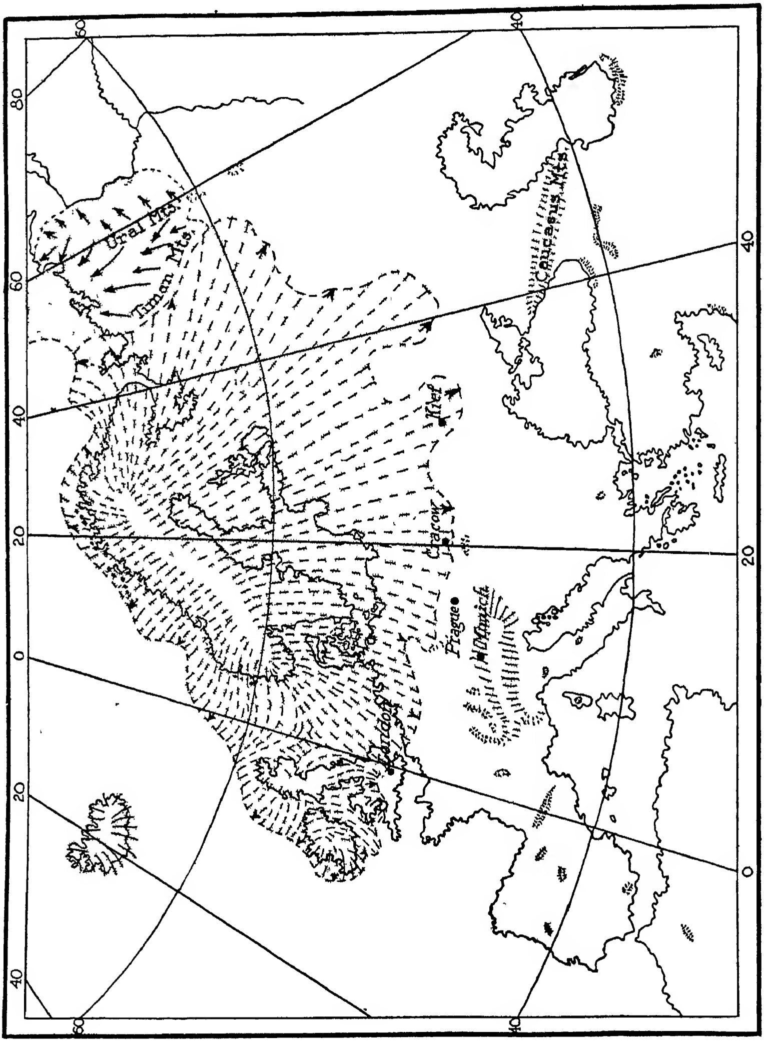


FIG. 528.—Europe during the epoch of maximum glaciation. (After James Geikie.)

with that of Great Britain. The Lower Forestian epoch is represented by peat bogs and buried forests in northwestern Europe. The land surface is thought to have been more extensive than now, and to have enjoyed a milder climate. The next glacial epoch, the Lower

Turbarian, is represented by "valley moraines and corrie moraines" in the higher regions, and by various sorts of non-glacial deposits elsewhere. During this epoch, glaciers locally descended to the sea

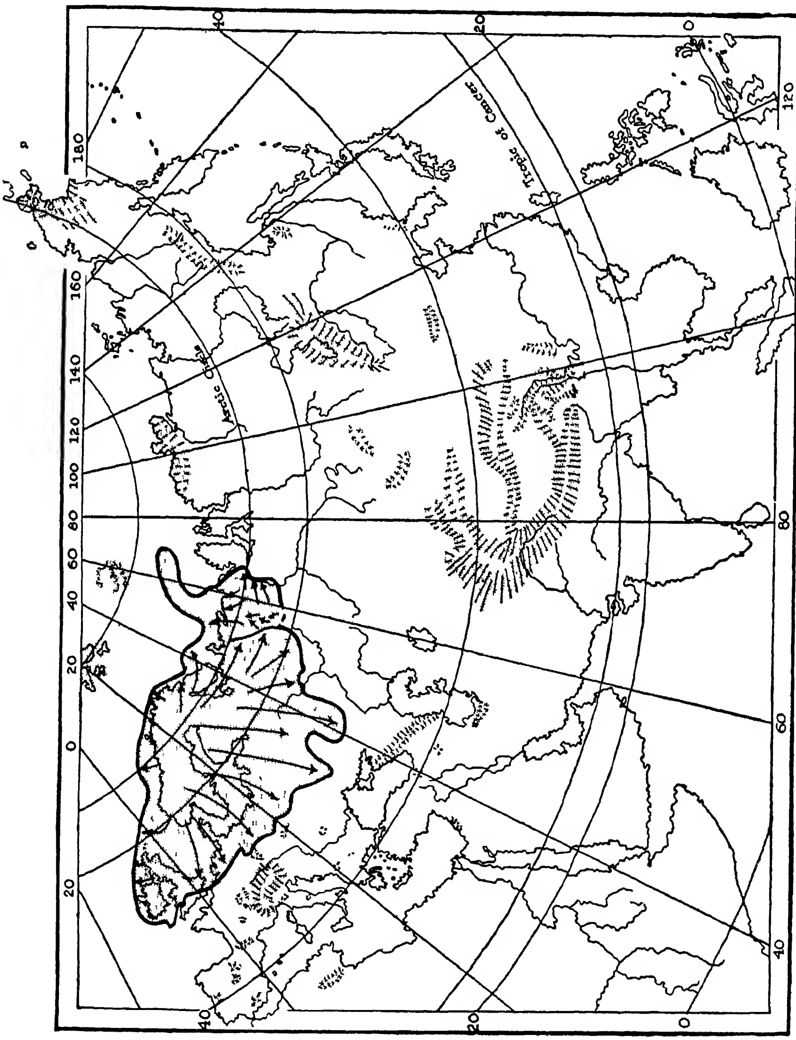


FIG. 529.—Glacial map of Eurasia. (After James Geikie.)

in Scotland. In the last glacial epoch, according to the above classification, the ice was still more restricted.

The preceding classification is not accepted by the German geolo-

gists, so far as it applies to Germany. They regard some of the separate epochs of Geikie as stages of a single epoch, and would reduce the number of glacial epochs to three, so far as their country is concerned.[1]

The deposits of several distinct glacial epochs have been recognized also in the mountains south of the ice-sheet, especially in the Alps.[2]

In other continents the glacial formations have been studied in detail in but few places, but recent studies in Turkestan indicate that the history of the glacial period in the Thian Shan Mountains was complicated, five glacial epochs being recognized.[3]

The loess of Europe and Asia has already been referred to. The eolian hypothesis of its origin seems to be gaining in favor, but other opinions have been held,[4] and still find advocates.

The Cause of the Glacial Period.

Many hypotheses respecting the cause of the glacial period have been offered, but none of them has, as yet, commanded the general assent of glacial investigators.

Almost all hypotheses appeal to a combination of agencies, but each centers more or less on some one agency which gives character to the hypothesis. Grouped by their characteristic agencies, they fall mainly into three classes: (1) those which appeal to elevation, the *hypsometric hypotheses;* (2) those which appeal to phenomena outside the earth, or to the relations of the earth to other bodies, the *astronomic hypotheses,* and (3) those which appeal to changes in the constitution or movements of the air, the *atmospheric hypotheses.*

Hypsometric Hypotheses.

The hypothesis of elevation.[5]—From the fact that alpine glaciation is a function of elevation, it was natural that one of the earliest hypotheses should postulate the lifting of the glaciated regions to the snow-line by a wide-reaching deformative movement. Auxiliary

[1] Keilhack, Jour. Geol., Vol. III, pp. 113–125.

[2] Penck, Die Alpen im Eiszeitalter

[3] Huntington, Explorations in Turkestan, Carnegie Institution.

[4] Skertchley and Kingsmill, Q. J. G. S, Vol. LI (1895), pp. 238–254.

[5] Dana, Manual of Geology, 4th ed., p. 970, and Upham, Am. Geol., Vol. VI, p. 327, and Am. Jour. Sci., Vol. XII, p. 33.

geographic changes would be a natural consequence of such a movement, and the effects of direct elevation and of attendant geographic changes have been variously combined in the different phases the hypothesis has assumed. As chief evidence of the elevation postulated, the buried valleys of the sea coasts, especially those of the northern latitudes, have been cited, and it is held by many advocates of this hypothesis that the 4000 feet or more of elevation thought to be indicated by the northern fiords, together with abetting geographic changes, were competent to produce the Pleistocene glaciation. Those who question this view doubt whether this elevation was contemporaneous with the ice development, and cite, as grounds for believing that it was earlier, the magnitude of the erosion indicated by the fiords compared with that which the glacial formations have suffered. They cite also the direct evidences that the valleys formed during this period of elevation were already present when the ice invasion took place. On the other hand, they offer evidences that the land was often lower than at present at certain important stages of the glacial period. It is explained by the advocates of the hypothesis of elevation that the glaciating effects must have lagged behind the elevation itself, and that the accumulation of ice might well have produced depression, and led to its own destruction.[1] It is not, however, clear to those who doubt the hypothesis that the glaciation should have lagged *so far* behind the elevation as to result in the great discrepancy observed between the erosion of the period of elevation, and the erosion of the earliest drift-sheets. The hypothesis of elevation also encounters difficulty in satisfactorily explaining the interglacial intervals which are now well established by abundant evidence, and also in accounting for the markedly mild climate of one or more of these intervals, which seems to imply a disappearance of the ice at least as complete as that of today. Unless some other agency than elevation be called into play, it seems necessary to postulate that a great elevation of a large part of two continents, followed by depression, was repeated as often as there were great oscillations in the ice development. The advocates of elevation have naturally questioned the adequacy of the evidence that the oscillations of the ice-sheets were really great, and they have usually held that the ice period was relatively short and

[1] On this point see Jour. Geol., Vol. II, 1894, p. 222.

simple. To escape the growing force of the evidence of frequent and important interglacial intervals, the older phase of the hypothesis has been amended by adding to elevation the main features of the Crollian hypothesis next to be sketched, which carries a postulate that involves climatic oscillations. The periods of these oscillations, however, are equal, while the observed oscillations seem to be notably unequal.

The elevation hypothesis also encounters grave difficulties when applied to the Permian glaciation of India, Australia, and South Africa, because of their low latitudes, because of the great height apparently required to furnish the necessary conditions for plateau glaciation, and because of the great oscillations necessary to account for the marine beds between the glacial beds. If the plateaus of Tibet and the Pamir, ranging from 15,000 to 18,000 feet above the sea, are not glaciated under present conditions, one cannot but wonder what elevation the southern peninsula of India would have required in the Permian period if elevation were the essential factor. No plateau outside the polar circles is now glaciated, except as the ice is derived from adjacent mountains, no matter what its relations to sea or land, to winds or currents, to moisture or aridity or other conditions. The observational basis for assigning the glaciation of a half of the North American continent to any elevation that can fairly be assigned to it, during either the Permian or Pleistocene period, is thus not as broad and firm as could be desired for a satisfactory working hypothesis.

Astronomic Hypotheses.

Croll's hypothesis.[1]—A semi-astronomical hypothesis was advanced by James Croll in the latter part of the last century, and for a time gained very wide acceptance in Europe, and found not a few adherents in America. The hypothesis is founded on variations in the eccentricity of the earth's orbit, combined with the precession of the equinoxes, together with the effects of meteorological and geographical influences, particularly the configuration of the Atlantic Ocean.

The orbit of the earth is slightly elliptical, and this ellipticity is subject to variations on account of the varying positions of the planets,

[1] Climate and Time in their Geological Relations; a theory of secular changes of the earth's climate, by James Croll, 1890, pp 312–328; also Climate and Cosmology, 1889, and The Cause of the Ice Age, Sir Robt Ball, 1893.

the upper limit being an eccentricity of 0.07. It is not claimed that this alters the total amount of heat received by the earth, or by either hemisphere, or even the proportions received during the periods between the equinoxes, which, according to Ball, are in the ratio of 63 for the summer to 37 for the winter, but that the *distribution* of heat within these periods is markedly affected by the shortening or lengthening of the two seasons, according as they fall in the perihelion or the aphelion portion of the orbit. In the perihelion portion there is a short season with much heat per hour, and in the aphelion portion a long season with less heat per hour. The precession of the equinoxes causes the seasons to shift relative to the perihelial and aphelial points. At present the earth is nearest the sun in our early winter, or in the early summer of the southern hemisphere. In 10,500 years the earth will be nearest the sun in our early summer, or the early winter of the southern hemisphere. We shall then have a shorter summer with more solar heat per hour, and a longer winter with less heat per hour. There have been differences of opinion as to how this change in the distribution of heat would affect glaciation. The Crollian hypothesis is built upon the belief that snow accumulation would be favored by the long winters, and snow-melting reduced by the short summers, notwithstanding their greater heat per diem.

It is conceded that the amount of eccentricity at present is too small to produce a very appreciable effect, otherwise we would have a glacial epoch now in the southern hemisphere. The eccentricity fluctuates in a very complicated way because of the varying attraction of the other planets on the earth, whose lines of attraction are constantly shifting, and are usually diverse and more or less mutually neutralizing. At long intervals, the planets pull measurably together and give relatively high eccentricity, but this never exceeds about four times the present amount. The hypothesis assumes that the relatively high eccentricity that is attained at these periods is sufficient to produce the essential conditions of the glacial period.

It is admitted that these astronomical relations are insufficient in themselves to produce the glacial effects observed, and so certain terrestrial conditions are made important elements in the working phase of the hypothesis. Prominent among these, it is held that the zone of the trade-winds and the thermal equator would be shifted from the gla-

ciated hemisphere toward the warmer one, and that this shifting would turn a large part of the warm equatorial waters away from the cooler hemisphere, intensifying the direct astronomical effect, while the warm water thus carried in excess into the warmer hemisphere would intensify the evaporating effects, and induce a mild and moist climate. Croll urged that this shifting would be peculiarly effective in the Atlantic, because of the angular form of the eastern coast of South America, and the critical position of Cape St. Roque relative to the equatorial currents. He held that a few degrees of southward shift of the trade-wind belts would throw a large part of the equatorial current south of Cape St. Roque, and turn it into the South Atlantic, greatly reducing both the existing contribution to the Gulf Stream and its auxiliary climatic effects, while, on the other hand, a northward shift, when the southern hemisphere was passing through its cold period, would throw nearly all the equatorial current north of St. Roque, and thus intensify the ameliorating conditions of the North Atlantic, and give a mild, moist interglacial epoch to the northern hemisphere. On this account especially he held that glaciation preponderated about the North Atlantic, and was less pronounced in other high latitudes.

A peculiarity of the hypothesis is that (1) the glacial epochs it postulates alternate between the northern and the southern hemispheres, and (2) that they are limited in duration to an appropriate fraction of the precessional period (21,000 years). This appropriate fraction is probably about that which effective winter bears to the whole year, for in the course of the precessional period, which may be conceived as an astronomical year, the attitude of the earth would pass through a stage of neutral distribution of heat between the glacial and the deglacial stages, very similar in nature to the conditions that produce our spring and fall. In the middle latitudes, the effective winter would perhaps occupy 5000 or 6000 years; in the high latitudes, one half or more of the precessional year, while in the equatorial belt, there would probably be little or no glaciating effects. These peculiarities of the hypothesis afford a means of testing it. If it be true, the glacial episodes should bear evidences of equal length; they should all be short, and they should be equally distant from each other in the same period of eccentricity. If the computations of the periods of eccentricity published by Croll are founded on adequate data (which has been questioned), there could only be a few alternations

of glaciation within a given period of high eccentricity, while none of them could be more recent than 60,000 years; indeed, Croll consistently placed the close of the glacial epoch 80,000 years ago.

The extended and critical glacial studies of recent years seem to show that the intervals between the different invasions are very unequal in time relations, and that the most recent is relatively young. It has also been found that glaciation was notably extended beyond its present limits on the lofty mountains of the equatorial regions. The progress of inquiry seems, therefore, to have weakened, rather than strengthened, the grounds of presumption in favor of this attractive hypothesis.

To appreciate the difficulties that arise from the shortness of the epochs of the Crollian hypothesis, it is to be observed that the Labradorean and Keewatin ice-sheets pushed out from what appear to have been their centers about 1600 and 1500 miles respectively. In making this estimate the centers are placed as far south as a fair interpretation will permit. If for a generous safety margin we place these centers of the initial snow-fields 500 miles farther to the southward, the edge of the ice-sheets had still to creep 1000 miles during the advancing stage of glaciation. To this is to be added its haltings and its retreating stages. It is to be noted that the advance of the frontal border of this ice-sheet is radically different from the movement of the ice itself, since the advance of the margin is only the *difference* between the rate of the ice movement and the melting of the margin. If one foot per day be allowed for the advance of the margin—an estimate much beyond the probabilities—it would take more than 14,000 years for the ice-edge to reach the extension observed. This is two thirds of the whole precessional period. If the safety margin of 500 miles be included, as it perhaps should be, and it be assumed that the accumulation of the central portion to a thickness sufficient to give effectual motion required as long a time per mile as its subsequent extension (since it took place in the initial stages of the glacial winter when its effectiveness was doubtless relatively small), the whole precessional period or more would be occupied in extending the ice the required distance. Nor is the difficulty essentially escaped by assuming that the snow-field grew up simultaneously over the whole area, or some large part of it, for numerous bowlders are found 600 or 700 miles from their nearest assignable sources, and 800 to 1000 miles or more from their

probable sources. To allow time for the residue of winter snow above summer melting to build itself up to a height capable of giving effective motion, and then to allow time to carry drift this great distance at any probable rate of motion, taxes the hypothesis very severely to say the least, for a high rate of motion probably cannot be assigned safely.

There is a widespread misapprehension as to the average rate of movement of the ice-fields of Greenland, which are almost our only available field of observation on the motion of continental glaciers. In certain fiords that lead out from great basins into which broad fields discharge their ice and their surface waters, and thus furnish the conditions for an extraordinary rate of movement, the rate of motion, at least during summer, is unusually high, and these exceptional cases have been taken as representative of the movement of the border of the inland ice. This is very far from being true. The average movement for the whole border of the ice field is quite certainly less than one foot per day, and is more likely less than one foot per week. The melting and evaporation at the edge of the ice fields of Greenland cut it back only a few feet per year, because of the shortness of the season and the covering of annual snow. Probably the wastage does not reach ten feet per annum. It is certainly much less than 10 feet in northern Greenland. If 12 feet be allowed for this, there should be an average advance of the edge of the ice of 40 feet, on the basis of one foot per week onward movement. This amount of advance for the 1400 to 1600 miles of ice border tributary to Baffin's Bay, would require the discharge of more than 1000 icebergs annually, averaging 100 feet in length and 300 feet in breadth, to remove the excess of ice and keep the margin of the ice-fields stationary, and this number of icebergs of these average dimensions exceeds the estimates of Rink and others. If the estimate were raised to one foot per day, the number of discharging icebergs would obviously greatly exceed the observed number. If the rate of advance be approached from the point of view of precipitation, computations show that either an enormous snowfall over vast regions or an almost total absence of melting and evaporation must be postulated to account for the building up of the great Pleistocene ice-sheets, and for developing their observed radial movements within such limited periods of time as the Crollian hypothesis requires.

The Crollian hypothesis encounters further serious difficulties when applied to the Permian glaciation of India, Australia, and South Africa, because of their low latitudes. The effect of eccentricity should be felt chiefly in the higher latitudes, and should be a vanishing quantity in the tropical belt. It is not clear how glaciation in the vicinity of the tropics could be explained on this basis, particularly in the Paleozoic era, unless the postulates of the atmospheric theory be also introduced to furnish favorable working conditions.

Other astronomical hypotheses.—Attempts have been made to found other theories on the eccentricity of the earth's orbit, and also to found them on variations in the obliquity of the ecliptic; but none of these has gained much acceptance. They have not been worked out with the care and detail which Croll gave to his hypothesis. They encounter most of the difficulties of the Crollian hypothesis, but in somewhat different forms.

There have been speculations upon the possible passage of the earth through cold regions of space, but there is no astronomical basis for them.

The recent determination of Langley and Abbot that the heat emitted by the sun varies as much as 10% within a short period, is very suggestive; but a short-period variation really has no direct application to a problem which requires a variation-period of tens of thousands, if not hundreds of thousands, of years.[1]

The hypothesis of a wandering pole.—It was early suggested that the axis of the earth may have been shifting its geographic position and that the Pleistocene glaciations were but polar glaciations of the existing type, distributed over northeastern North America and northwestern Europe by an excursion of the pole through 15° or 20° of latitude. So long as the theory of a thin crust resting on a liquid nucleus, and capable of sliding over it, perhaps under the differential influence of the tidal pull, was accepted, the mechanical difficulties of this hypothesis did not seem insuperable; but if an effective rigidity of the body of the earth be accepted, as now seems almost necessary, the dynamic obstacles become extremely formidable, for no agency capable of producing such a change in the axis seems rationally assignable. When a few years ago it was discovered that changes of latitude were actu-

[1] Astrophysical Jour., Vol. XIV, 1904, pp. 305-321.

ally taking place so rapidly as to be detectible in the course of a few months, and when it was found in the progress of field studies that the Alaskan-Asiatic side of the northern hemisphere was not generally glaciated, as the Atlantic side was, there seemed some little hope that a wandering pole might offer the solution of the glacial puzzle. The polar movement, however, proved to be limited to a returning curve of very small radius, without evidence of secular wandering. Geological research also failed to show that there was the northward shift of the warm zones on the unglaciated side of the globe which the hypothesis required.

Atmospheric Hypotheses.

In the discussion of the origin and nature of the early atmosphere and its dependence on feeding and depletion (Vol. II, p. 93), we have endeavored to develop a conception of the general atmospheric conditions of all the ages that would at least not be inconsistent with glaciation in the early Cambrian, or the Permian, or at any other stage in the earth's history at which a suitable combination of conditions might be presented.

I. Variations in depletion the working factor.—In the discussion of the problems of the Permian, we have endeavored to connect atmospheric conditions with causes springing fundamentally from deformation of the earth, and entering into the complex outworkings of the periods following such deformations.

The deformations of the Pliocene may be presumed to have produced effects on the atmosphere similar to those produced by the post-Carboniferous deformations. The general discussion there given (Vol. II, p. 658) may therefore be regarded as applicable to the Pleistocene glaciations, so far as the general atmospheric conditions are concerned, merely recalling (1) that the oceanic circulation was interrupted by the extension of the land; (2) that vertical circulation of the atmosphere was accelerated by continental and other influences; (3) that the thermal blanketing of the earth was reduced by a depletion of the moisture and carbon dioxide in the atmosphere, and that hence the average temperature of the surface of the earth and of the body of the ocean was reduced, and diversity in the distribution of heat and moisture introduced. The *general conditions for glaciation* are

thus supposed to have been supplied, conditions without which all more special and local causes would be inoperative.

Two serious problems, however, remain: (1) the localization of the Pleistocene glaciation, which, though not so remarkable as that of the Permian period, was yet very extraordinary, and (2) the periodicity expressed in a succession of glacial and interglacial epochs which formed a declining series of very unequal lengths.

1. **Localization.**—The localization[1] is assigned to the two great areas of permanent atmospheric depression that have their present centers near Greenland and the Aleutian Islands respectively (Figs. 530 and 531). It is within these permanent cyclonic areas that the exceptional glaciations of Greenland and Alaska occur at present. There is also a remarkable correspondence between the border of the ice-sheets and the courses of the moving storms on the borders of these permanent cyclonic areas. It is also notable that the great ice-lobes converged toward the area where the storm-frequency is now greatest. It is not a little remarkable that the ice-sheets after their several retreats, and perhaps entire disappearances, should have advanced repeatedly in nearly the same forms and to nearly the same extents, though in some particulars their habits otherwise were noticeably unlike. All these and many minor facts are associated in theory with these permanent "lows" and the related storm-tracks. These features are presumed to have been extended and intensified during the glacial stages, but to have retained the general relations and configurations they now possess. The basal cause of these features is probably to be found in the configuration of the land and water of the northern hemisphere.

2. **Periodicity.** — The periodicity of glaciation under this hypothesis is assigned to a rather complex interaction of a combination of agencies which is not susceptible of brief statement without more qualification than our limits will permit, if it is to be wholly accurate and fully protected against misinterpretation; but the leading features may be sketched and the necessary qualifications must be taken for granted.

The basal conception is that, under general conditions favorable

[1] An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis. Jour. Geol., Vol. VII, 1899, pp 752–771. See also discussion of localization under Permian, Vol. II, p. 674.

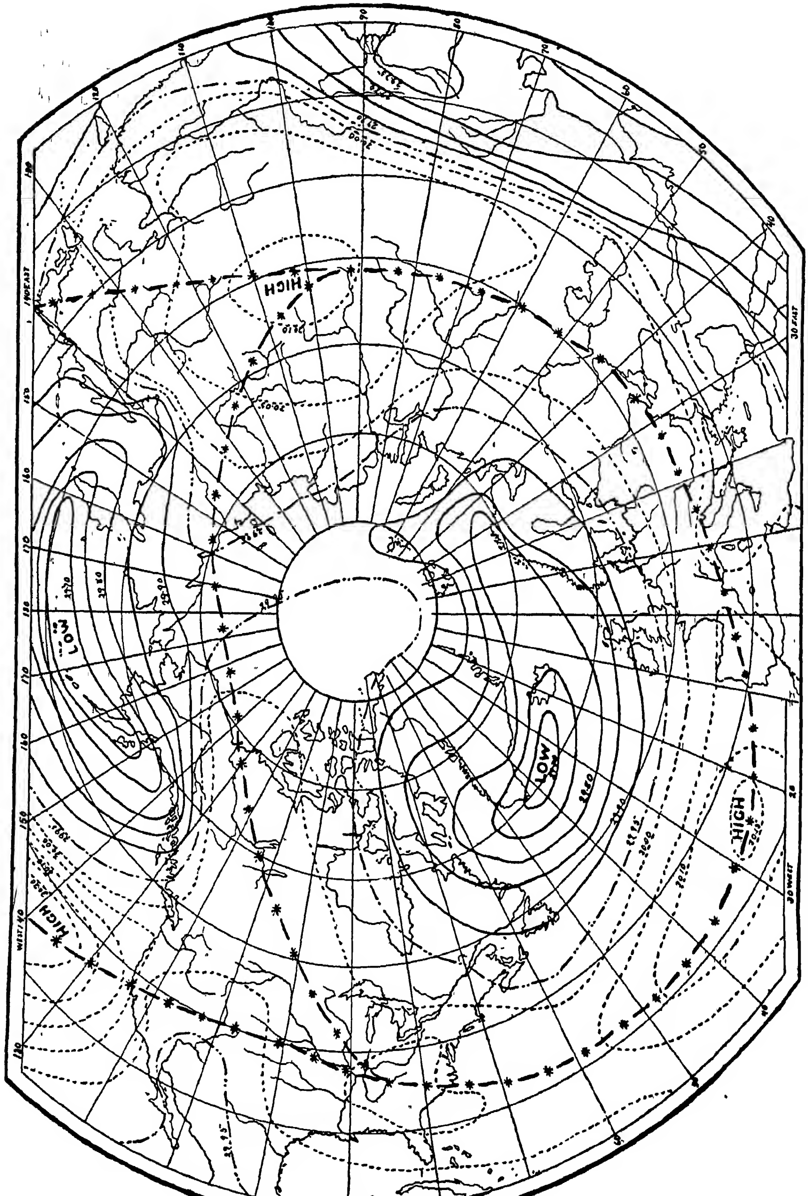


FIG. 530.—Isobaric lines for the north polar region for the year. (Buchan.)

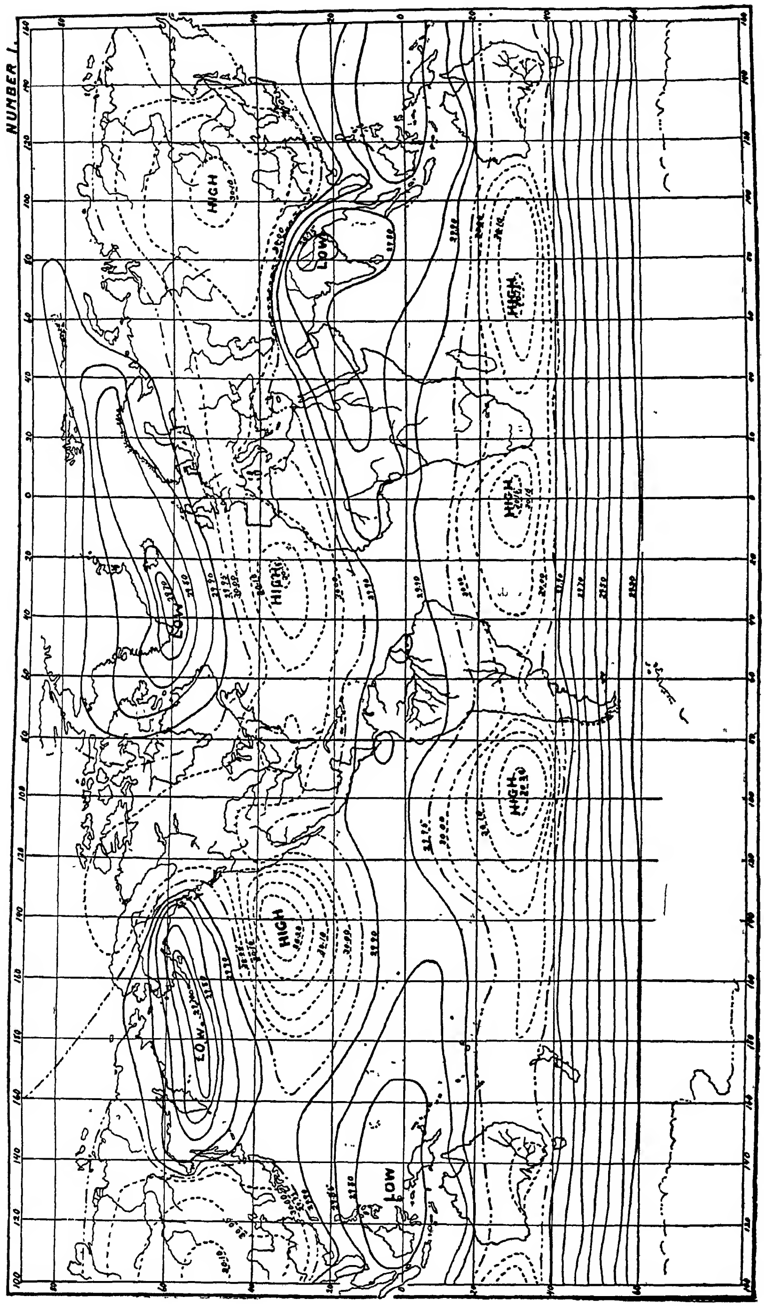


FIG. 531.—Isobaric lines of the globe for the year. (Buchan.)

for glaciation, certain of the agencies involved became dominant and tended to intensify and accelerate glaciation for a time, until they either pushed the effects to an extreme from which a reaction was inevitable, or they exhausted themselves temporarily, while other agencies of opposite phase, which had been subordinate until then, became dominant and forced a reaction.

When a reaction was set up, it in like manner was pushed to an extreme, and deglaciation extended beyond the point of equilibrium for the average conditions. And so oscillations beyond and short of the mean state, gave a rhythmical phase to the glaciation of the period. The rhythm, we learn from observation, took the form of a series of sub-equal oscillations with declining time-intervals. There seem to have been no great differences in the amplitude of the ice advances. Observation does not permit us to speak as confidently of the extents of the recessions. It is important to note that the fundamental or general conditions remained effective throughout the period, and that the oscillations are regarded only as rhythms superposed on these general conditions. The more intense phases of these rhythms were, however, the only portions of the series that recorded themselves in glaciation near the borders of the glaciated areas, and were perhaps the only portions that recorded themselves in continental glaciations at all. The retrocessional phases may have been recorded only in cool climates in high latitudes, and in glaciation at high altitudes.

Among the specially intensifying agencies that are thought to have pushed glaciation to its climaxes, the following are recognized:

1. The higher carbonation of the ocean necessary to bring its carbon dioxide into equilibrium with that of the atmosphere at the lower temperature that had been induced by the general conditions, especially in the high latitudes. This lower temperature of the water gave the sea a higher coefficient of absorption of carbon dioxide. (See previous discussion under Permian, Vol. II, p. 665.)

2. A special process of super-carbonation of the ocean through the agency of freezing in high latitudes, which coöperated with the above.

3. A reduction of the organic extraction of lime and the other bases of the bicarbonates, which otherwise would have freed carbon dioxide.

4. An increased reflection from the snow-fields and hence a reduced

retention of solar radiation, abetted by an increase of ice-clouds and frozen fogs, which have high reflective power, low specific heat, and low diathermacy.[1]

5. A progressive reduction of the moisture in the air, and hence a decrease of its blanketing effects.

6. Some minor agencies that may be passed by.

These were opposed by the following:

1. The giving forth of carbon dioxide from the ocean because of the reduced pressure of the carbon dioxide of the air, as the latter was consumed.

2. A reduction of the contact area between land and air by the growth of the ice-fields, and hence the checking of the carbonation of the rocks.

There was a residual effect arising from changes in the amounts of vegetal growth, animal life, and organic decay, that was felt on the one side or the other, but it is not easy to strike the balance. Probably, the ratio of animal life to vegetal growth was rather higher than before, as the carbon dioxide declined, as the relative amount of oxygen increased, and as the cold increased; but decay was probably also checked, and the formation of peat and similar residues of organic matter promoted. On whichever side it may have fallen, the balance was probably not very important.

It will be noticed that these opposing agencies came into effect only after the glaciating agencies had done such part of their work as brought these opposing agencies into activity; and hence they lagged behind the effects they tended to offset. For example, the diffusion of carbon dioxide from the ocean to the air requires time. Its effects could only be felt some time after those of the cause of the diffusion. Besides, interchange between the main body of the ocean and the air was especially retarded by the surface layer of fresh uncarbonated water that came from the melting of sea-ice, and even of the land-ice, and by the superficial layer especially affected by pelagic life.

The checking, at length, of the glacial acceleration, is assigned to the following agencies, particularly the first:

1. The completion of the higher carbonation of the ocean, followed

[1] The specific heat of ice is 0 504, that of water being unity. For diathermacy, see Preston's Theory of Heat, pp. 466, 467, 1894.

by a reversal of the process, in which the ocean gave forth more carbon dioxide than it received.

2. The cumulative effects of the ice-covering in reducing the carbonation of the rocks.

When once the extension of the glaciation had been checked and a retrocession begun, the following agencies are thought to have abetted it, and forced it, in turn, to an extreme.

1. The reversal of the oceanic action, by which it gave out in the warm regions more carbon dioxide than it absorbed in the cold regions, and thus lost its higher state of carbonation.

2. The increase of the secretion of lime in the ocean, setting free the second equivalent of carbon dioxide of the calcium bicarbonate. This was due to increasing warmth of the ocean and to the spread of the shallow sea-border on the land as the result of the return to the ocean of the water previously locked up in the ice, the warmth acting both through dissociation and through lime-secreting organisms.

3. An increase in the moisture in the air, and hence an increased absorption and retention of solar radiation.

4. A reduced reflection from the snow-fields, ice-clouds, and frozen fogs, and the substitution of the more thermally absorbent dark earth, water-clouds and fogs.

The cumulative effects of these and some minor agencies are presumed to have pushed the glaciation back to a state appreciably beyond that required by the average effects of the agencies involved, and hence to have prepared the way for a new stage of aggressive glaciation. The agencies are thought to have been competent to produce entire deglaciation of the lowlands, in the longer interglacial epochs. They are not thought to have been able to restore the deep oceanic circulation to the pre-glacial state, but only to check and change the carbonating effects.

In all this period of oscillation it is assumed that there was an average supply of atmospheric material from the original sources, external and internal. This might of course have varied, and such variations must be taken into account as modifying and possibly even interrupting the processes just outlined; but in discriminating the effects of the latter, an average contribution from the sources of supply is assumed. It is possible to build up a hypothesis of climate on the variations of atmospheric supply, as will be noted later.

Only a selected portion of this complex process can be further discussed here. The factor that most probably controlled the periods of the glacial oscillations, as it seems to us now, was the reversal in the carbonation of the ocean, and this seems to have bearings of value beyond this immediate problem.

Let the climatic conditions of the Tertiary period, when figs and magnolias grew in Greenland, be taken as the point of departure. At that time, as apparently at all times, the evaporation and the absolute humidity of the air in the low latitudes was greater than in the high latitudes. The general circulation of the atmosphere between the equatorial and polar regions resulted in a loss of humidity in the latter regions, and a gain to the ocean, whose surface was slightly raised and freshened. This gave rise to superficial currents toward the warm zone, to restore the equilibrium. These were gradient currents, for the added waters, though cold, were lighter than the ocean brines.[1]

There was inevitably some mixing of the fresh and salt water, and some of the latter was also carried toward the warm latitudes. In the warm dry latitudes, the excess of evaporation gave rise to increased salinity and density, and the denser salt waters are assumed to have sunk and spread poleward, constituting a counter-current to balance the salt-water element of the equatorward currents. The fresh-water element of the surface circulation had its counterpart in the atmospheric circulation. The flow initiated in the evaporating zone was a density current, due to salinity, notwithstanding its superior warmth. This warm dense water, descending and flowing poleward, must at length have been forced to the surface in high latitudes, and contributed its warmth to them. This is assigned as one reason for the warm temperatures of the high latitudes in those periods when this kind of deep-sea circulation prevailed.

The validity of this conception of the deep-sea circulation in such periods is based on the conviction that superior evaporation in the low latitudes was more efficient in inducing high density, than the inferior temperatures in the high latitudes. That this was at least

[1] It is to be borne in mind throughout this discussion that an increase of salinity is likely to be more effective in increasing density than is a lessening of the temperature. Because of the peculiar behavior of water near the freezing-point, the specific gravity at the freezing-point of salt-water is about the same as at 12° C.

possible may be inferred from the fact that the range of density-effects for a range of temperature of 30° C., is about 0.004, while the range due to salinity may be 0.028 or more. The probable ranges were, however, much less wide apart, and this circulation is not a deduction wholly beyond question.

The water thus thought to be carried down and poleward from the equatorial regions was carbonated under the conditions of equilibrium then prevalent in the low latitudes. Because of the high temperature there, the carbonation of this poleward flowing water was relatively low, and the main body of the ocean would be sub-carbonated, i.e., carbonated below an ideal equilibrium for the average temperature, for the average content of carbon dioxide in the air, and for the average carbonates in the sea. In the glacial period, when freezing in high latitudes was brought on by the general lowering of temperatures, the salts and gases of the sea-water must have been largely forced out of the ice, and passed into the layer of water next below, which thus became super-charged with salts and carbon dioxide.[1]

In being cooled before freezing, the sea-water, under normal conditions, absorbed carbon dioxide, because the coefficient of absorption for carbon dioxide was raised by the cooling. The sea-water should, therefore, have been more highly charged with this gas than the average ocean even before the freezing took place, and hence was specially super-carbonated.

The layer of water below the sea-ice, thus super-carbonated and rendered heavy by super-salinity, tended to descend and flow toward the equator. Thus the depths of the ocean were slowly filled with cold, super-carbonated water, displacing the previous warm, sub-carbonated water.

[1] A portion of the carbon dioxide thus concentrated probably escaped into the air when opportunity was afforded by seams and lanes in the ice, but the greater part doubtless followed the course of the dense water in which it was dissolved. An illustration of the incidental effects of this process is probably given in the exceptionally high content of carbon dioxide found in the air at certain times in Grinnell Land and Greenland. (Moss, Notes on Arctic Air, Proc. Roy. Dublin Soc., Vol II, 1880, and more fully, Krogh, Abnormal CO_2 percentage in the air of Greenland, etc., Meddelelser om Gronland, Vol. XXVI, 1904, pp. 409–411) At present the Arctic ice drift is concentrated toward Greenland and the islands west of it, and the waters below are doubtless more or less carried with the ice and discharge some of their super-charge of carbon dioxide into the air.

But as soon as the great depths were filled, and these super-carbonated waters themselves rose to the surface in the warm zones, they must have given forth not only the super-charge of carbon dioxide they then retained, but, because the coefficient of absorption was lowered by the rise of temperature, they must have given forth a portion of what was their normal content in the cold zone. It is obvious, therefore, that as soon as the new circulation was well established, its output of gas in the lower latitudes must have equaled or surpassed its intake in the higher, incidental qualifications aside. The circulation was then no longer a source of atmospheric depletion. The whole ocean body had been raised to the higher state of carbonation required by the lower temperature. Not only this, but the process was reversed; for the intake in the high latitudes had been decreasing since the carbon dioxide of the atmosphere had been declining as the result of the very process of loading up the ocean, and the surface-waters that entered the freezing zone were lower in carbon dioxide than they had been at the start, and hence the concentration by freezing was less effective. This was not true of the salts, so far as this process was concerned, and hence the circulation was not effected by the reduced carbonation. At this stage, therefore, the atmosphere began to be enriched in carbon dioxide, and the reverse swing of the oscillation was inaugurated.

If this reasoning be valid, the length of the previous stage of higher carbonation of the ocean becomes a matter of concern. It is probable that the deep-sea circulation is affected by other factors than those of low temperatures and increased salinity in the polar regions. It has been thought that the winds of the North Atlantic tended to heap up the waters in the Arctic Ocean, and thus to induce a return current below, in addition to the recognized Labrador current at the surface. While this may be true in this instance, because of the configuration of the North Atlantic, it is not obvious that, for the whole world, the pole-ward winds would be more effective on the ocean surface than the opposite winds. Rather might one suppose that the colder air moving equator-ward would, on the whole, flow more largely at the bottom of the atmosphere, and be the more influential on the currents of the ocean. If the winds, on the whole, promote deep-seated circulation from high to low latitudes, they would shorten the periods of carbonation and decarbonation; if the opposite, they would lengthen them.

The depths of the ocean are now filled with water but little above the freezing-point, which implies a deep-seated movement from the polar regions. This goes to show that diffusion, mechanical mixture, friction, agitation transmitted from the surface, tidal and earthquake motions, and the internal heat of the earth, all combined, do not more than slightly modify the dominance of this circulation as a means of determining the temperature of the deep sea, and hence there is still less reason to question its dominance in determining the saline and gaseous content of the deep-sea waters, for only the first two of the agencies tend to diffuse these constituents. The form of the super-carbonation is indeed changed by the solution of minute calcareous shells that fall from the ocean surface, and are dissolved before they reach the greatest depths, as shown by the Challenger investigations; but the carbon dioxide so used becomes free again when the calcium carbonate is again secreted by plants or animals. The point of moment here is that the process is essentially one of circulation, and is not essentially modified by diffusive processes, and hence that the time-period is closely measured by the great cycle which carries the whole body of the ocean through its concentrating action. The relatively rapid surface circulation of the ocean has little to do with this.

According to the observations of Peary [1] and Nansen [2] the first season's freezing at the points of their observations, which may be called mid-arctic, reaches depths of 4 to 8 feet. That of subsequent seasons, when the old ice remains, is appreciably less. In the center of the frozen seas, the old ice forms a persistent covering. If a layer of new ice as much as 5 feet in thickness were formed annually over an area of 9,000,000 square miles—about the area of the Arctic and Antarctic Oceans combined, according to Murray—a mass of water equal to that of the whole ocean would pass through the freezing process in about 33,000 years; if the annual layer were 3 feet thick, in about 55,000 years; if 2 feet, in about 83,000 years. This implies a movement equal to the amount of freezing only, and a correspondingly high concentration of salt and gas. A greater movement and a less concentration are much more probable, and hence a shorter period for the super-carbonating epoch. There is a considerable list of modifying conditions, the most of which would apparently tend

[1] Personal information.

[2] Scottish Geog. Mag., Vol. XIII, 1897, p. 240.

to reduce the period, and the uncertainties of this estimate are not unlike those relative to the length of a glacial advance or retreat, but the period thus estimated is of the same general order of magnitude as that of the glacial stages, and nothing beyond such a similarity in order of magnitude is to be expected. During this process of higher carbonation of the ocean, the advance of the ice was reducing the area of the land exposed to carbonation, and was thus reducing the carbonation of the rocks. This checking of the carbonation on the land coöperated with the reversal of sea-action in the inauguration of an ice retreat.

As warmth increased there should have been, normally, an increase of lime-secreting plants and animals, and these would have secreted more lime individually, as a rule, setting free more of the second equivalent of carbon dioxide of the calcium carbonate. The moisture in the air should have increased with the increase of warmth and the melting of the ice-fields. This new combination gained in force as the ice was removed. It is assumed that the coöperative force of this combination, once in dominance, maintained its superiority over the opposing agencies until the ice-sheets were largely or wholly removed, and the freezing that had inaugurated the oceanic super-carbonation ceased to be effective.

When the full land-surface was again exposed to carbonation, and the air had been re-enriched in carbon dioxide, and the oceanic circulation had carried the most highly carbonated portions of its waters to the surface in low latitudes, and had begun to bring up the relatively low carbonated portion that had descended in high latitudes after the carbon dioxide had become depleted to its lowest state, the conditions were ripe for a new process of depletion and glaciation under conditions closely similar to the previous one. The process could thus be repeated until the *general conditions* that brought on the glaciation ceased to be effective, and the conditions for re-inaugurating a movement toward a mild uniform climate were restored. It is not presumed, however, that the oceanic circulation was reversed in the interglacial stages, but that the super-carbonation in the high latitudes was reduced to an ineffective measure, or stopped entirely. In a climate that permitted pawpaws and osage oranges to flourish in eastern North America above latitude 43°, and induced lions, leopards, hippopotamuses, etc., to invade the middle latitudes of Europe, an

essentially complete suspension of the formation of sea-ice may be assumed with much reason. Obviously, the succession of such glaciations and deglaciations could only continue so long as the general conditions that brought on the glaciation continued to prevail. So soon as they passed away, the oscillating series ceased.

This hypothesis is dependent on the efficiency of carbon dioxide and water-vapor as thermal absorbents. While this is conceded for the water-vapor, and measurably for the carbon dioxide, the quantitative efficiency of the latter has been questioned. This has been touched upon in the Permian discussion, and it will only be added here, that if a lowering of the average temperature of the globe from 5° to 8° C. below the present temperature would be sufficient to produce the general conditions of glaciation, as has been estimated, a direct efficiency of carbon dioxide to the extent of 1° or 2° C., with the coöperation of the water-vapor and accessory agencies, would probably produce the requisite effects. In the Sahara, the lowness of the moisture in the air often permits the temperature to fall from mid-day heat to 0° C., during the night. If there were no atmosphere at all above the Sahara, the temperature would undoubtedly fall 100° to 200° C. more during the night. That it does not do so is due to the efficiency of the remaining constituents of the atmosphere. Their value as coöperating factors has been greatly underestimated. By mathematical computations, based on Langley's observations on the heat received from the moon, Arrhenius some time since deduced a much higher estimate of the thermal efficiency of the carbon dioxide of the atmosphere than the glacial problem seems to require.[1] More recent experimental determinations give notably lower results. The later results of Arrhenius[2] himself seem still to be more than sufficiently high, while those of Rubens and Aschkinass[3] and of Ångström[4] do not seem fatally low, though they have been so interpreted.

Objection has been made to the sufficiency of the consumption of carbon dioxide to produce the effects assigned rapidly enough to meet the requirements of the case, on the ground that the tendency to equilib-

[1] On the influence of carbonic acid in the air upon the temperature of the ground. Phil. Mag., 1896, pp 237–276.

[2] Kosmische Physik, II, p. 503.

[3] Ann. Phys. u. Chem., 1898, p. 598.

[4] Ibid., 1900, p, 321.

rium between the carbon dioxide of the air and that of the ocean would require the whole oceanic content to be reduced proportionally with the reduction in the atmosphere. But this view seems to neglect (1) the very slight efficiency of diffusion; (2) the limitation of agitation to a comparatively shallow surface layer; (3) the effects of life in this surface layer; (4) the interference of uncarbonated waters arising from ice melting; (5) the long period of circulation necessary to bring about an interchange between the body of the ocean and the atmosphere; (6) the part played by temperature in this interchange; (7) the part played by ice-formation, and (8) fundamentally, the change in the basis of equilibrium itself.

II. Variations in supply the working factor.—As already noted, the foregoing hypothesis makes the depletion of carbon dioxide by chemical union or by oceanic absorption, the working feature, while variations in the supply are regarded as modifying elements not easily discussed at present, because the distribution of volcanic action, regarded as the chief variable, is not well determined. It is possible, however, to reverse the point of view, and regard the variation in the supply of carbon dioxide as the working factor and variations in consumption the modifying ones. This latter, if we have not misapprehended, is essentially the view of Arrhenius [1] and Hogböm.[2]

The working application of this form of the hypothesis would be rather markedly different from that sketched above, but it has not been worked out into detail, so far as we are aware.

III. Proximate hypotheses.—In the atmospheric class of hypotheses are to be reckoned two that are proximate but not ultimate hypotheses: namely, the cloud hypothesis,[3] and the wind hypothesis.[4] Without doubt clouds and wind are important factors in the development of glaciation; but if clouds are made the essential factor, the problem is only shifted to the cause of such persistent clouds covering such large areas for tens of thousands of years consecutively, with a cooling potency competent to develop the great ice-sheets. The solution of this seems as formidable as the problem in its usual form. Much

[1] Loc. cit.

[2] Svensk Kemisk Tedskrift, Bd VI, 1894.

[3] Manson, Am. Geol, Vol. XIV, 1894, pp 192–194, Vol. XXIII, 1899, pp 44–57, and Vol XXIV, 1899, pp. 93–120, 157–180, 205–209.

[4] Harmer, Geol Soc. London, 1901; Abstract in Geol. Mag., 1901, p. 327.

the same may be said of the suggestion that glaciation was due to a change in the prevailing direction of the winds. Some notable modifications of the winds must probably be factors in any complete glacial hypothesis, but the causes and conditions that determined these are scarcely less problems than glaciation itself. While no theory is ulteriorly without dependence on unsolved factors, a theory of a geologic phenomenon is relatively complete when it is carried back to the general course of events that form geologic history, such as deformation, geographic changes, or astronomic relations.

Formations Outside the Ice-sheets.

While the glaciation of middle and high latitudes was the most striking event of the Quaternary period, by far the larger part of the earth's surface was not affected directly by the ice. Outside the area of glaciation, the commoner phases of erosion and deposition were in progress, and non-glacial Pleistocene formations are wide-spread, though by no means universal. Degradation in some places was the antecedent of deposition in others, and under the varied conditions of the period, various classes of deposits were made, among which were the following:

(1) *Eolian deposits*, conspicuous along many sea and lake shores, along many rivers, and in sundry arid and semi-arid regions, and inconspicuous as a dust mantle in every lodgment area, for wind-blown dust is essentially ubiquitous. (2) *Fluviatile deposits* were made (*a*) by streams which had no direct connection with the ice, and (*b*) by those which had such connection. These deposits occur along essentially all streams of low gradient, and along many streams where the gradient is not low. Kindred deposits were made by sheet-floods and temporary streams, even far from the courses of permanent streams. They are common at the bases of most slopes, where they are often more or less mixed with talus. (3) *Lacustrine deposits* of both the glacial and non-glacial types, comparable to the two classes of river deposits, were formed not only in existing lakes and more or less generally about their borders, but over the sites of the numerous lakes which have become extinct since the beginning of the period. (4) Characteristic deposits were made by *springs*. (5) *Terrestrial organic deposits* (peat, calcareous marl, etc.) abound in many of the ponds and marshes

to which glaciation gave origin, and also, though less commonly, outside the area directly affected by the ice. (6) *Marine deposits* were made on lands submerged during the Pleistocene period, and doubtless over essentially all of the ocean bottom. The areas where such deposits have since emerged are chiefly confined to narrow belts along the coasts. (7) *Volcanic rocks* of Pleistocene age are found in our continent, chiefly west of the Rockies, though volcanic dust is widely distributed on the Great Plains.

These non-glacial deposits probably appear at the surface over a larger area than the formations of any earlier period. In the aggregate, they are more extensive and more readily identified than deposits of like origin referable to any earlier period. If the subaërial deposits of other periods were equally extensive, they have been largely buried, destroyed, or so modified as to lose their distinctive characteristics.

The average thickness of the Pleistocene deposits is not great. Glacial drift and Pleistocene accumulations of débris at the bases of mountains are sometimes several hundreds of feet thick, and in rare cases even more; but otherwise the thickness of non-glacial Pleistocene deposits rarely exceeds a few score feet.

On the Atlantic and Gulf Coasts.

On the Coastal Plain of the Atlantic and the Gulf of Mexico, there is a wide-spread but thin body of gravel, sand, loam, and clay, referred to the Pleistocene period. In altitude it ranges from sea-level up to several hundred feet, though most of it lies below 200 feet. All of the non-glacial post-Tertiary deposits of the Atlantic and Gulf plains were formerly grouped together under the name *Columbia.*

Soon after the Columbia formation was differentiated[1] it was found to be bipartite, and the terms "High-level Columbia" and "Low-level Columbia" were applied to the two divisions in the type area, the District of Columbia.[2] Further study has disclosed the fact that the materials formerly grouped under the one name represent at least three somewhat distinct stages of deposition.[3] Physically

[1] McGee, Am. Jour. Sci., Vol. XXXV, 1888, p. 367.

[2] McGee, 7th Ann. Rept, U. S. Geol. Surv., 1885–86.

[3] Reports of the State Geologist of New Jersey, 1897–1900. The *Bridgeton*, *Pensauken*, and *Cape May* Formations.

two of the three divisions do not differ notably from each other, but their topographic and stratigraphic relations are such as to indicate that a very considerable interval of erosion elapsed after the deposition of the first, before the deposition of the second. The third subdivision of the original Columbia formation is much younger than the others; is, indeed, of last-glacial and post-glacial age.

As originally defined, the Columbia formation was said to have a fluvial and an extra-fluvial phase. Applied to the Atlantic coastal plain, this subdivision means that along the valleys leading from the mountains and the Piedmont plateau to the ocean, the Columbia formation is thicker and composed of coarser and more heterogeneous materials, than over the inter-stream areas. In the latter position the formation is composed, in considerable part, of materials derived from beds close at hand; in the former, it is composed of materials from all parts of the drainage basin above the point of its occurrence. In the valleys, the gravel, sand, and loam are more distinctly separated from one another than in the inter-valley areas, and stratification is more distinct. To the northward, the heterogeneity of composition increases as the border of the glacial drift is approached. On the whole, the formation thickens toward the coast, but is nowhere known to attain great thickness.

The oldest subdivision of the original Columbia formation is found at higher levels than the second phase. In the principal valleys it constitutes broad but often rude terraces, which rise up-stream. Thus up the Potomac, the Susquehanna, the Delaware, and other valleys, they rise to altitudes notably above those attained by the extra-valley phase of the formation.

In the type locality, the Low-level Columbia covers rock terraces 100 feet or so below the high-level phase of the series (Fig. 532). The relations of the two subdivisions indicate that extensive erosion followed the deposition of the high-level Columbia, and that the broad valleys then developed were subsequently aggraded by sediments similar to those of the preceding epoch of deposition. The two deposits are so nearly alike in composition that their separation is based chiefly on their topographic relations.

In areas of slight relief, the distinction between the high-level and low-level phases of the Columbia is not always marked topographically, and the differentiation is then difficult or even impossible.

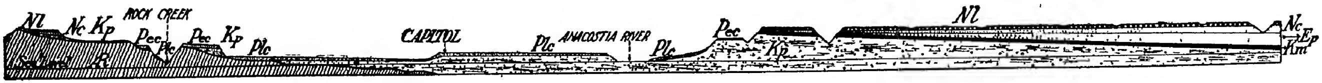


FIG. 532.—Section through Washington, D. C., showing the relations of the high-level (*Pec*) and low-level (*Plc*) Columbia. *Æ*= Archean; *Kp*, Comanchean (Potomac); *Km*, Cretaceous (Matawan); *Ep*, Eocene (Pamunkey); *Nc*, Chesapeake; *Nl*, Lafayette. (Darton, U. S. Geol. Surv.)

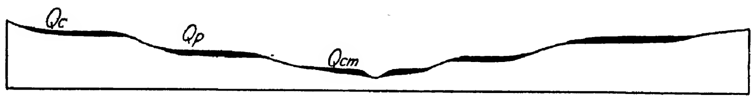


FIG. 533.—Diagram showing the relations of the three divisions of the Pleistocene as seen in valleys. *Qc*=the high-level Columbia, *Qp*=the low-level Columbia (or Pensauken), and *Qcm*, the Cape May formation.

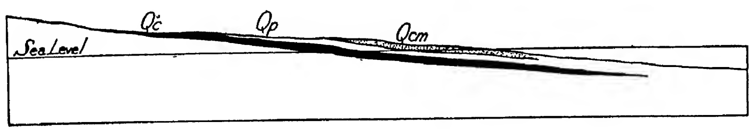


FIG. 534.—Diagram showing the theoretic relations of the three principal subdivisions of the Pleistocene outside the valleys, along a line normal to the coast. The letters have the same significance as in Fig. 533.

Even in such cases, however, there is abundant evidence that the series is not a unit in origin. Locally at least, deposition probably alternated repeatedly with erosion, in the course of the history of the Columbia series. Even where the topographic distinction between the two most marked divisions of the series is not pronounced, there is evidence of one interval of erosion more important than others, and this may well correspond with the time of pronounced erosion between the high- and low-level members of the series in the type area.

The third phase of the composite Columbia is found at still lower altitudes, along the streams and coasts. Its disposition is such as to show that the second phase of the Columbia formation had been somewhat extensively eroded before the deposition of the third. In the valleys formed during this interval of erosion, and along the coast at accordant levels, the third member of the series finds its chief development. Its relations, as shown along the valleys, are diagrammatically represented by Fig. 533. Outside the valleys, the landward edge of this member of the series is as ill-defined as the landward edge of the older members in the inter-stream areas. Fig. 534 shows, diagrammatically, the supposed relations of the three phases along an interfluvial tract, from the coast inland. This figure represents the seaward margin of the oldest subdivision, as buried by the next member of the series, and the seaward margin of the latter, as covered, in turn, by the youngest subdivision. It should be understood that this relation is diagrammatic, since no section showing the three subdivisions in such superposition has been seen. Since the deposition of the third phase of the formation but little erosion has taken place. It should also be understood that the three subdivisions are probably not sharply separable from one another, because of the manner in which the deposition took place (see p. 452).

The threefold division of what was originally called the Columbia formation calls for a change in nomenclature. It is convenient to have a name for this coastal series as a whole. If the name Columbia be used in this way, its several subdivisions should have separate names. In New Jersey, the name *Bridgeton* has been applied to what is probably the equivalent of the High-level Columbia, and the name Sunderland was later applied to the High-level Columbia of Maryland. The name *Pensauken* [1] has been applied in New Jersey to what is prob-

[1] Report of the State Geologist of N. J. for 1894, p. 105.

ably the equivalent of the Low-level Columbia farther south, and this name may well be given to the second subdivision of the original Columbia. For this subdivision the name Wicomico has been used in Maryland. To the youngest phase of the formation the name *Cape May* [1] has been applied, from one of its typical localities. In Maryland this subdivision has been called the Talbot formation.

Over all the preceding formations, Bridgeton, Pensauken, and Cape May, and perhaps extending even beyond the oldest and highest of them, there is a thin and discontinuous deposit of loam, which in some places seems to represent a phase of deposition distinct from all the preceding. Similar loam sometimes covers the glacial drift of last-glacial age. Its interpretation is still an open question.[2] It is very probable that different parts have originated in different ways. In many places the loam has sufficient thickness to obscure the relations of the underlying formations.

Stratigraphic relations.—The various members of the Columbia series rest unconformably on inferior formations. On the Atlantic Coast, the older divisions often rest on the Lafayette formation, and often on terranes from which the Lafayette had been eroded before the deposition of the Columbia series.

Fossils.—The Columbia series rarely contains fossils. At a few points, however, shells of fresh-water molluscs have been found in the Pensauken but a few feet above the present sea-level.[3] Marine shells have been found in gravels which are perhaps of Pensauken age, on the east coast of New Jersey. Such evidence as the few fossils afford, therefore, is against the marine origin of at least parts of the formation. The Cape May formation, like the older Pleistocene formations of the Atlantic Coast, is generally without fossils, but marine shells have been found in it at a few points (southern New Jersey) a few feet above sea-level,[4] and about Philadelphia marine diatoms have been found in the loam which covers it, up to an altitude of 40 to 60 feet.

[1] Report of the State Geologist of N. J. for 1897, p. 20.

[2] See Report of State Geologist of N. J. for 1897, p. 20, and Vol. V, Glacial Geology of N. J.

[3] Report of the State Geologist of N. J. for 1896, p. 205.

[4] Report of the State Geologist of N. J. for 1885, and Geology of Cape May County 1859.

The origin of the Columbia and associated formations.—The origin of the Columbia formation presents much the same problems as that of the Lafayette, and is probably to be explained in much the same way; that is, the series is looked upon as largely fluviatile and subaërial, the result of land aggradation. The occasion for renewed deposition on the Coastal Plain in the Quaternary period probably lay (1) partly in changes of gradient incident to crustal warpings, and (2) partly in the climate of the period. Renewed upward bowing

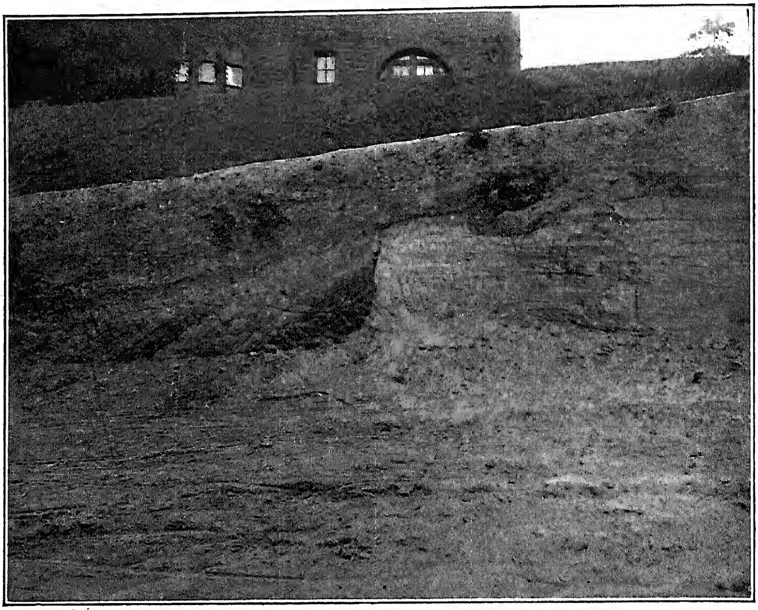


FIG. 535.—Unconformable contact between the Columbia formation and the Potomac, Washington, D. C. (Darton, U. S. Geol. Surv.)

of the Appalachians and of the plateau to the east of them probably stimulated the streams descending from them to increased erosion, and the deposition of a part of their loads on the plain below was a natural result. Under these circumstances, deposition would probably have extended up the valleys to altitudes considerably greater than those of the plain where the principal deposition took place. The poor assortment of the material, the common cross-bedding, the numerous trifling unconformities, and the absence of fossils, all are consistent with this interpretation. So also is another feature of

the constitution of the material deposited. One of its common constituents is crystalline rock, now generally thoroughly decayed. This material points to conditions when erosion and transportation exceeded rock decay, as might be the case after the development of increased declivity.

The second factor, the climate, contributed to the same end. The climate of the period was changeable, and at least periodically cold, as the recurrent ice-sheets show. Under these conditions a larger proportion than now of the precipitation of the Appalachians was doubtless in the form of snow, and this was favorable to the flooding of streams during the melting seasons. At the north, the deposition of the Columbia material was probably partly by water coming directly from the ice of the early glacial epochs. Floating ice helped to transport the bowlders of the formation, and so to give it the heterogeneity which is one of its distinctive features, especially in proximity to the glacial drift. In this way also, the presence of large bowlders of soft shale, scores of miles from the nearest outcrop of similar rock, may be explained.

The cold climate probably affected erosion, and therefore deposition in another way, for the reduction of temperature was probably attended by a reduction of vegetation, and any diminution of vegetation must have reflected itself in increased erosion. The reduction of vegetation was probably greatest just where erosion was most readily stimulated, namely in the higher altitudes. The importance of this consideration has perhaps not been duly recognized.

It is conceived, therefore, that the deposition of the principal subdivisions of the Quaternary series of the Coastal Plain resulted from the combined effect of surface warping and climatic change; that epochs of notable deposition alternated with epochs when erosion was dominant in the same regions; and that the materials of each principal stage of deposition were deposited, shifted, and re-deposited repeatedly, so that the Bridgeton (High-level Columbia), the Pensauken (Low-level Columbia), and the Cape May formation, are each really complex series, though they nowhere attain great thickness.

While the Cape May division of the Quaternary was being deposited, the sea transgressed some parts of the present coast to a slight extent at the same time that deposition was taking place in the valleys scores of miles inland, and in some cases hundreds of feet above sea-level.

If similar relations existed during the earlier stages of Quaternary deposition, the seaward edges of the deposits of each principal stage of deposition may be marine. It is probable also that the series contains estuarine phases of sedimentation, and it can hardly be doubted that each subdivision now recognized on the land has its equivalent (in time) marine phase beneath the sea.

The essential contemporaneity of the Cape May formation with the last glacial epoch, seems to be indicated by the phenomena of the northern part of the Coastal Plain, and it seems not improbable that the earlier members of the Quaternary system of the coast were connected with earlier glacial epochs.

In recent times, dunes have been developed at numerous points along the coast, and their development and destruction is still in progress.[1] Humus deposits also have somewhat extensive development in the tidal marshes, and to a less extent elsewhere.

In the Interior.

Some of the non-glacial Pleistocene formations of the interior, notably the loess, the valley trains, etc., have been referred to in connection with the glacial drift. Apart from such formations, there are others which seem to be measurably or wholly independent of the ice.

The wide-spread gravels of the western plains, largely of late Tertiary age, have been referred to, but the deposition of gravels in this region probably continued into the Pleistocene, is indeed still in progress. In the general absence of fossils, and with the slight measure of study which has been devoted to them, Tertiary and Quaternary gravels have not been sharply differentiated in the interior. The deposits of this class are largely fluviatile.

In some sandy regions, and along some valleys, there are tracts and belts of dunes for which the semi-arid conditions are favorable. Perhaps the most considerable area of dunes is in central Nebraska, where an area of 24,000 square miles is said to be covered by them.[2]

[1] See for example, the Norfolk, Va.-N. C., folio, U. S. Geol. Surv.

[2] Darton, 19th Ann. Rept. U. S. Geol. Surv., Pt. IV; see also topographic maps of Camp Clarke, Browns Creek, and St. Pauls sheets, and the folios of the state, published by the U. S. Geol. Surv.

Similar areas, though less extensive, occur in Kansas.[1] Dunes are also conspicuous along many valleys in Kansas (see Fig. 2, Pl. II, Vol. I) and elsewhere. Small dunes are of common occurrence locally in the humid region east of the Great Plains. Thus they abound about the head of Lake Michigan and along its eastern shore, and along some streams, especially those flowing through sandy tracts. Even where dunes are wanting, wind-blown sand and dust are widespread, though, excepting the loess, not generally in such quantity as to be readily recognized. Much of this eolian sand is of very recent deposition.

Erosion, rather than deposition, was the great feature of the Quaternary in the interior, outside the region affected by the ice-sheets; and in the erosive work, wind, running water, and ground-water have coöperated.

In the West.

The Quaternary formations of the west belong to all the several categories mentioned on p. 446,and to this list must be added the glacial formations, not especially considered in the earlier part of this chapter. But few of these various sorts of deposits have received close study over any considerable area, though something is known of all. Among the deposits which have been most closely studied are those of some of the numerous lakes which existed at various points west of the Rockies. Those of the Great Basin are best known (Fig. 536.)

Lacustrine Deposits. Lake Bonneville.[2]—The most considerable of the western Pleistocene lakes was Lake Bonneville, the body of water of which Great Salt Lake is the diminutive descendant. Its basin is believed to have been due to crustal deformation, and to have antedated the lake itself by some considerable period. Previous to the formation of the lake, the basin is thought to have been arid, a conclusion based on the great alluvial cones and fans subsequently covered by the lake. During the pre-lacustrine period of aridity, such quantities of debris from the surrounding mountains were brought into the basin as to bury the bases of the mountains to depths of perhaps 2000 feet, at a maximum.

[1] See the Pratt, Syracuse, Larned, and Kinsley sheets, U. S. Geol. Surv.
[2] Gilbert, Mono. I, U. S. Geol. Surv.

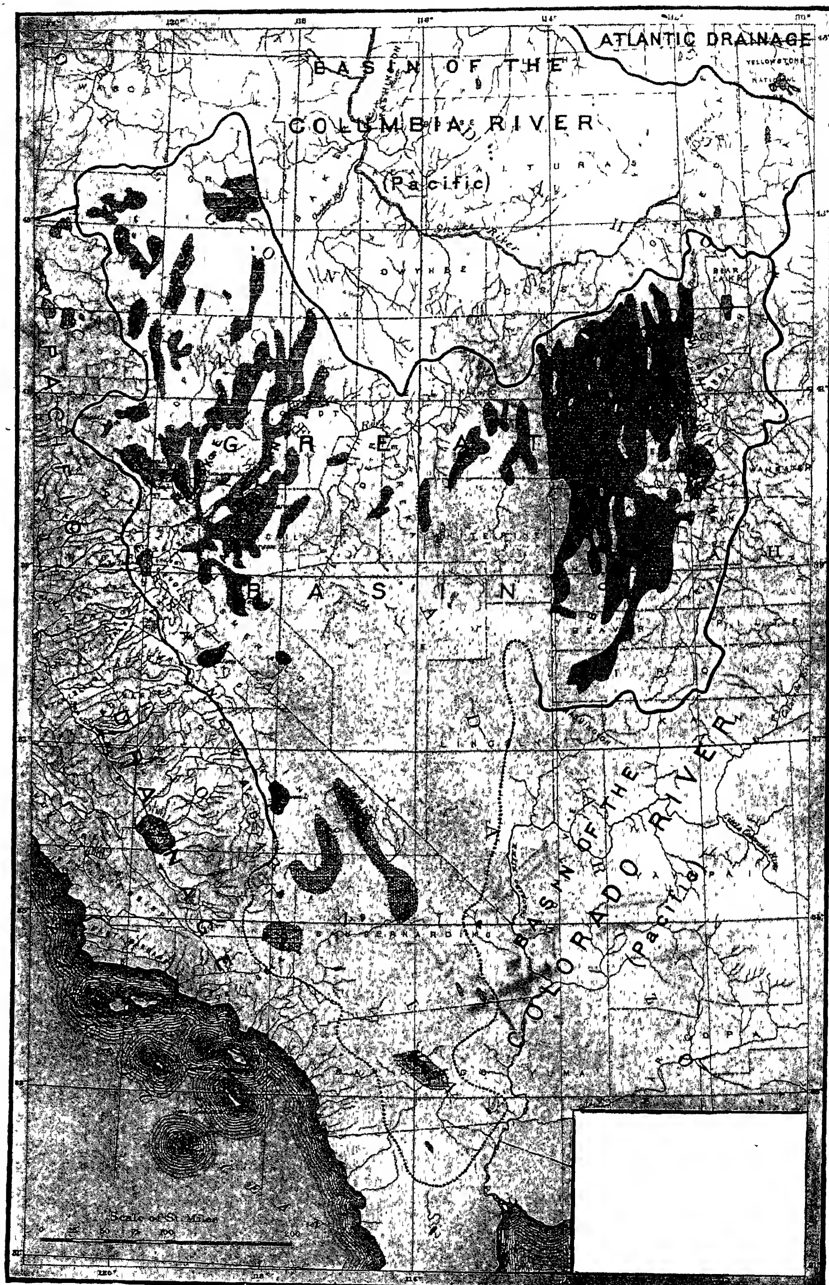


FIG. 536.—Map showing the position and area of the Quaternary lakes of the Great Basin. (Gilbert, U. S. Geol. Surv.)

Following this period of aridity, the climatic conditions were such that a large lake was brought into existence; but after enduring for a

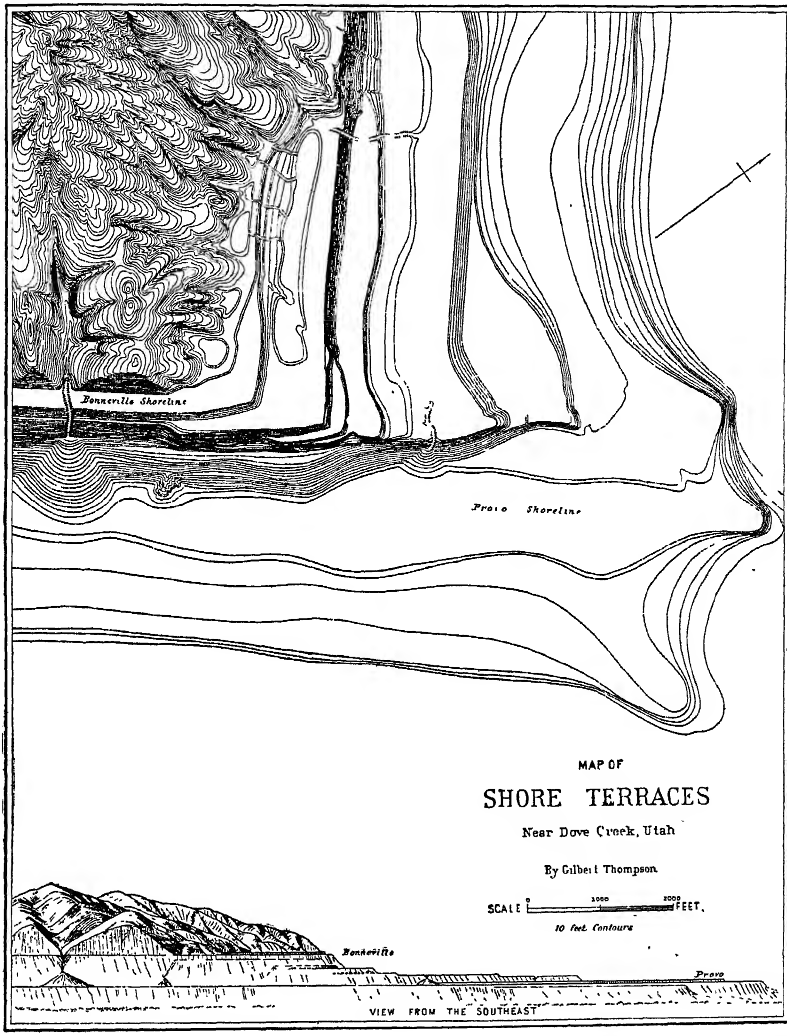


FIG. 537—Contour map of the shore terraces of Lake Bonneville, near Dove Creek, Utah, with sketch of same below. (Thompson, U. S. Geol. Surv.)

time, it disappeared, apparently by desiccation resulting from change of climate. Later, the lake was restored, and its water rose some 90 feet higher than before, and found an outlet to the northward.

The maximum stand of the water is recorded in various topographic forms characteristic of shores. The outflow of the lake cut down the outlet 375 feet, and at this new and lower level, distinct shore marks were developed. Later, evaporation from the lake again became more considerable than precipitation and inflow, and the lake gradually shrank to the present dimensions of Great Salt Lake. At its maximum, Lake Bonneville was more than 1000 feet deep, and had an area of more than 19,000 square miles; the maximum depth of Great Salt Lake is less than 50 feet (its average less than 20 feet) and its area but about $\frac{1}{10}$ that of its ancestor.

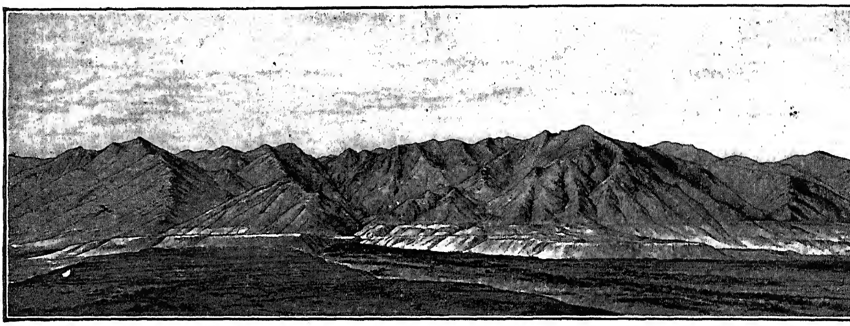


Fig. 538.—Ancient deltas of Logan River, at Logan, Utah. (Gilbert, U. S. Geol. Surv.)

As the lake dried up, its waters became separated into numerous basins, corresponding to the lowest parts of the Bonneville bottom. Some of these basins, besides that of Great Salt Lake, contain, or have recently contained, lakes. Others have playas in their lowest parts, where water gathers after every rain, but does not persist. Great Salt Lake is apparently doomed to still further decrease by the diversion of water from the feeding streams for purposes of irrigation.

Terraces, deltas, and embankments of other sorts were developed about the shores of Lake Bonneville wherever the appropriate conditions existed (Figs. 537–539), and the aridity of the climate since the lake sank below them, has allowed them to remain with little modification by erosion. As the lake dried up, deposits of salts were made, among which sodium chloride and sodium sulphate are most abundant. Gypsum crystals are plentiful, and in places they have been heaped up into dunes. Great Salt Lake is estimated to contain 400,000,000 tons of common salt, and 30,000,000 tons of sodium sulphate. Both

are extensively utilized. Calcium carbonate, though not shown in quantity by analyses of the water, is precipitated in the form of oölite about the shores of the lake, probably through the influence of organisms.

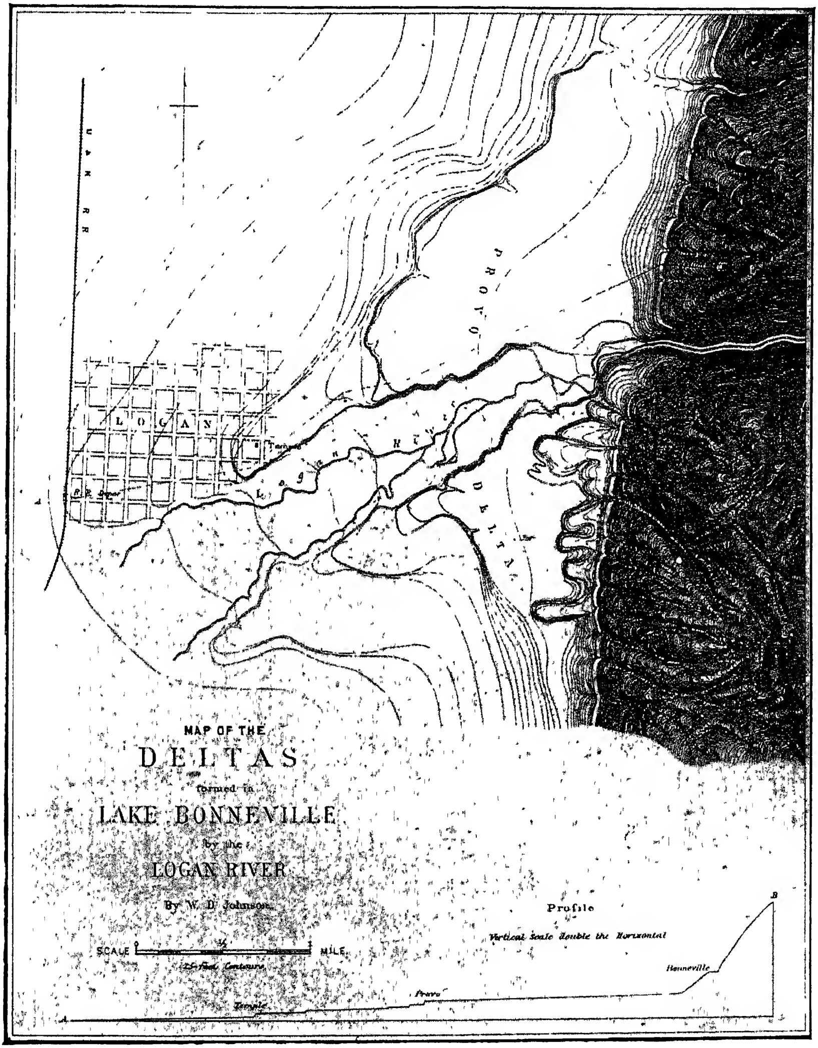


FIG. 539.—Same as Fig. 538, in contours. (Johnson, U. S. Geol. Surv.)

Within the area of Lake Bonneville, igneous eruptions (Fig. 540) have taken place during the Pleistocene period. These eruptions appear to have occurred at various stages of the lake's history, and even in post-

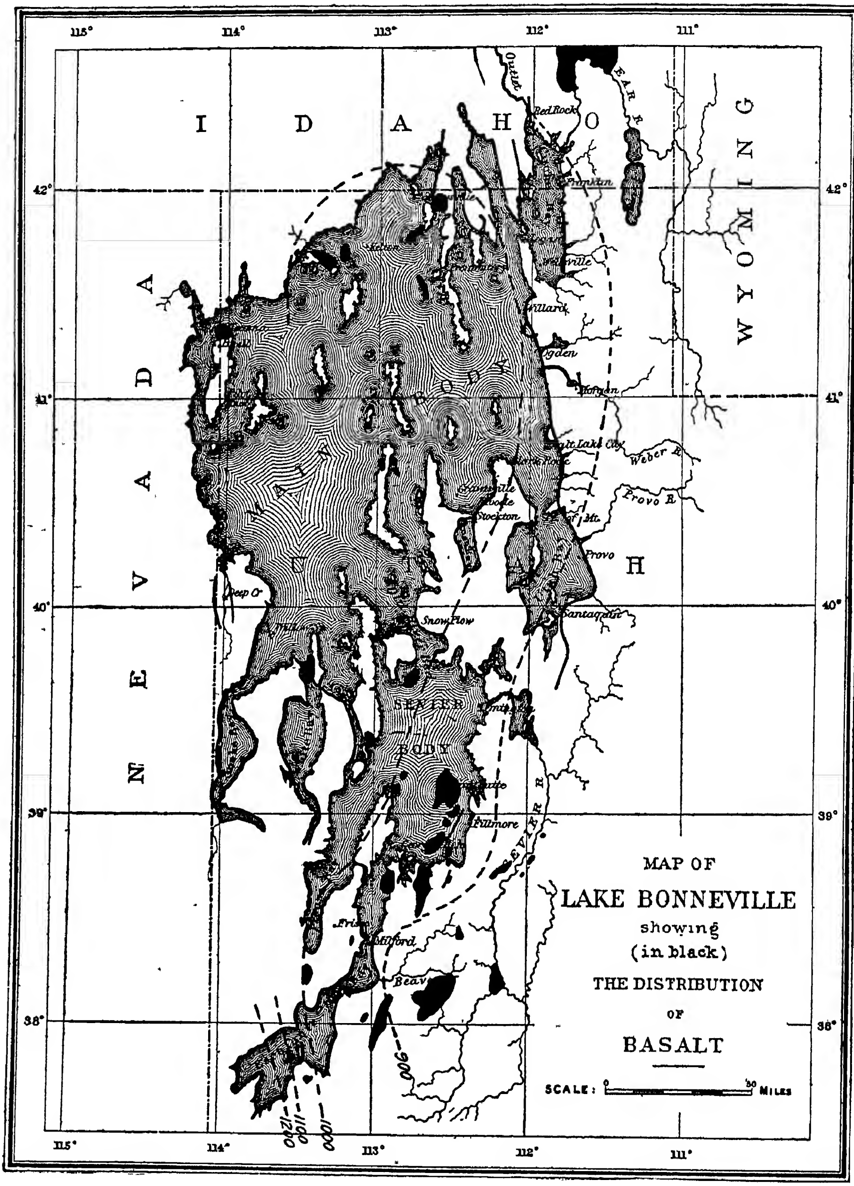


FIG. 540.—Map of Lake Bonneville, showing also the areas of basalt (black areas), some of which are Quaternary, the lines of recent faulting (full black lines), and the deformation of the basin (dotted lines). The figures on the dotted lines show the height of the Bonneville shore line above the level of the present Great Salt Lake. (Gilbert, U. S. Geol. Surv.)

Bonneville time. Since the Bonneville stage, too, there has been faulting in the basin (Figs. 541–542). At the west base of the Wasatch

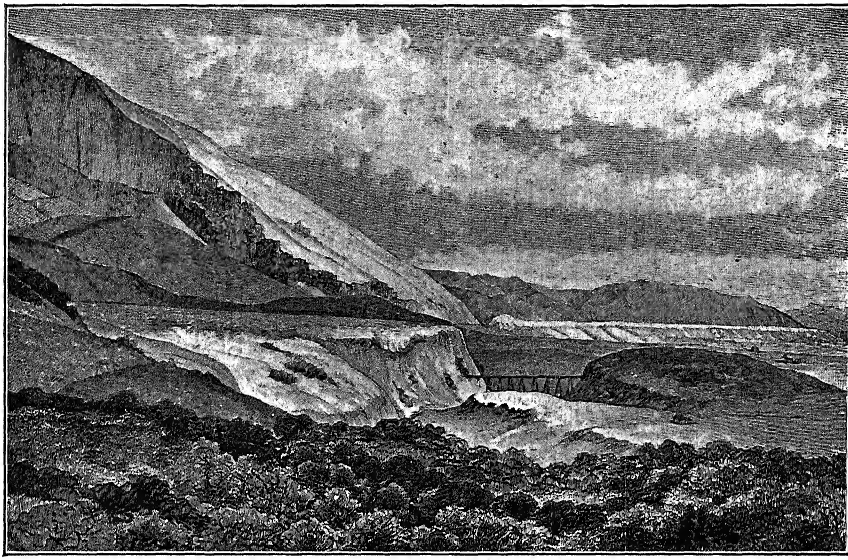


FIG. 541.—The trough in the middle foreground was produced by faulting; near the mouth of Little Cottonwood Canyon, Utah. The trough is in glacial drift. (Gilbert, U. S. Geol. Surv.)

range, faulting has affected the Bonneville terraces, with displacements of as much as 40 feet. At other points where post-lacustrine faulting has been observed, the throw is less.

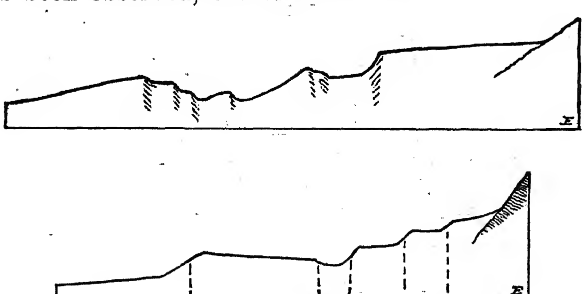


FIG. 542.—Fault scarps in the moraine at the mouth of the Little Cottonwood Canyon, Wasatch Mountains. (Gilbert, U. S. Geol. Surv.)

The diastrophic activities of the region have not been confined to faulting. The shore lines of the former lake have been deformed

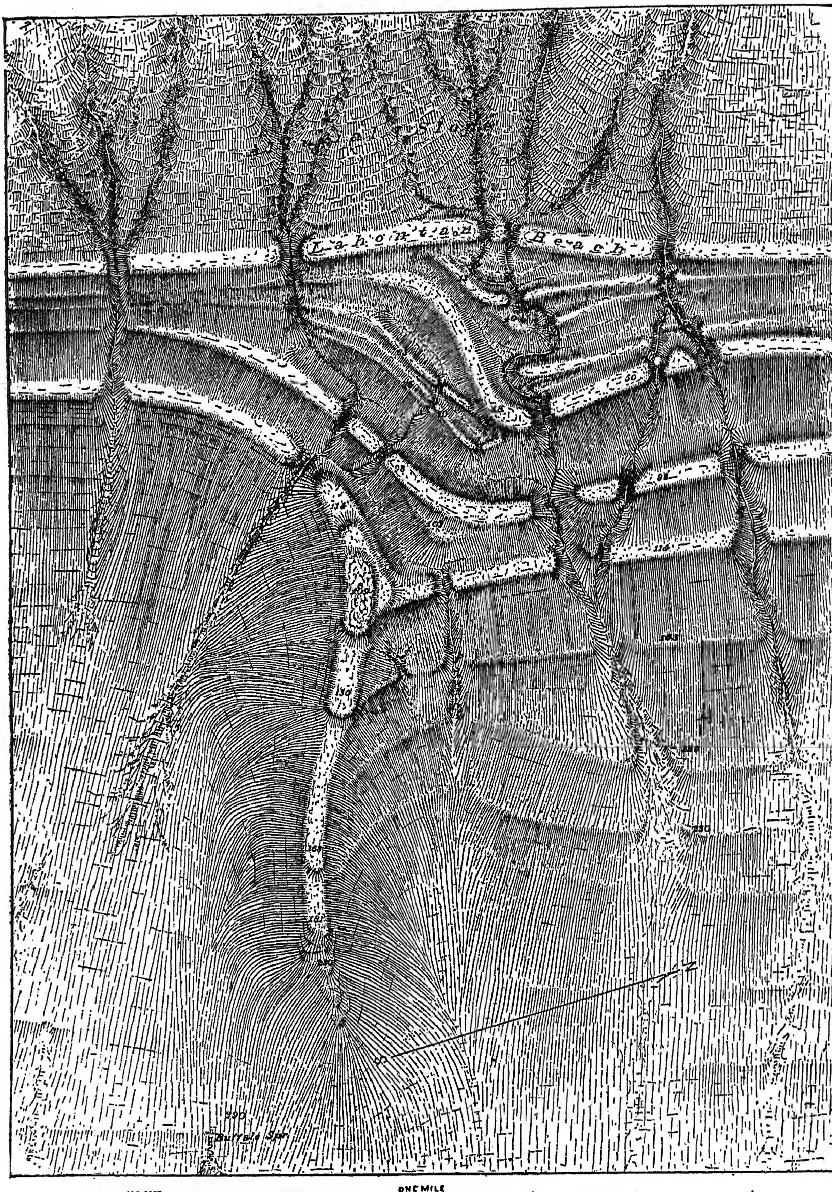


FIG. 543.—Gravel embankments along the shore of Lake Lahontan at Buffalo Springs, Nev. (Russell and Johnson, U. S. Geol. Surv.)

to the extent of more than 300 feet; that is, some parts of the Bonneville shore line are more than 300 feet higher than others (Fig. 540). This deformation affects even the later and lower shore lines, and stands in no intimate relation to the faulting of the region.

Lake Lahontan.[1]—Farther west, but still in the area of the Great Basin, were other lakes, probably contemporaneous with Bonneville. The largest was Lake Lahontan, a lake of most irregular outline (Figs. 536 and 547), the history of which was similar to that of Lake Bonneville. The basin of Lake Lahontan is thought to have been due to the displacement of faulted blocks. As in the case of Bonneville, a condition of aridity preceded the lake. When increased humidity brought

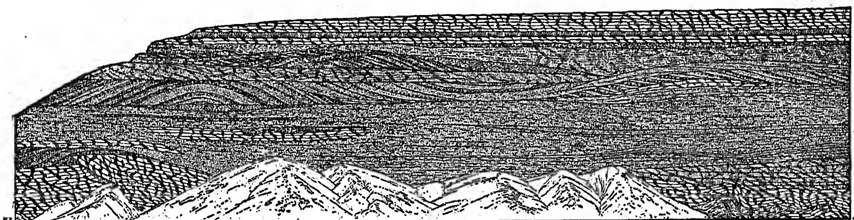


FIG. 544.—Section of Lahontan sediments, near Agency Bridge, Truckee Canyon Nev. (Russell, U. S. Geol. Surv.)

the lake into being, its waters rose until they covered an area of nearly 9000 square miles. This stage of the lake, like the first stage of Lake Bonneville, was followed by a period when the lake nearly or quite disappeared. Later, it was restored, and its waters rose about 30 feet higher than before, but did not find an outlet. The two stages of high water in Lake Bonneville and Lahontan have been thought to correspond with epochs of glaciation in the adjacent mountain regions.

At some stages of the lake's history, the condition of the water was such as to allow mollusks to live in it, while at other stages it appears to have been so saline as to have prevented its habitation. These facts point to considerable fluctuations in the climate during the history of the lake.

The deposits in Lake Lahontan are comparable to those in Lake Bonneville (Figs. 543 and 544), but among the clastic sediments are found thin beds of volcanic ash, and the relative importance of the chemical precipitates is greater. The main precipitate was calcium

[1] Russell, Mono. XI, U. S. Geol. Surv.

carbonate, which, in the form of calcareous tufa, was deposited during at least three distinct stages of the lake's history (Fig. 545). The

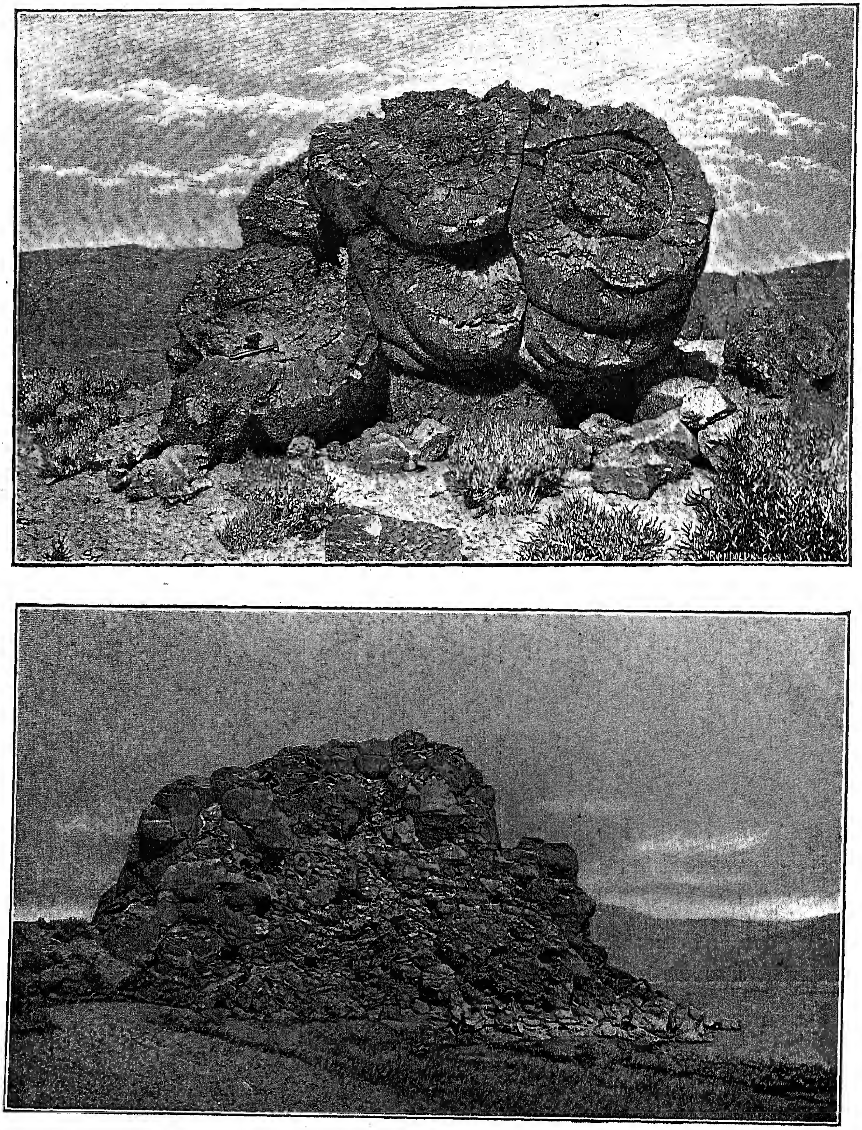


FIG. 545.—Tufa deposits in the basin of Lake Lahontan. (Russell, U. S. Geol. Surv.)

oldest tufaceous deposits lined the basin of the lake at the time of its first expansion; the next were made when the lake was low, between

the two stages of expansion; and the youngest were made at the time of the last expansion. Oölite was deposited at some stages of the lake's history, and is now making about Pyramid Lake. In some parts of the Lahontan basin there are deposits of salt, and salt is also derived from brine wells.

Subsequent to the last stage of expansion, the waters appear to have been completely dried up. The period of maximum desiccation is thought to have been no more than 300 years ago. Since then the humidity of the region has so far increased as to develop small lakes in the deeper parts of the former basin.

All lines of evidence point to the shortness of the time since Lakes Bonneville and Lahontan existed. The embankments of sediment

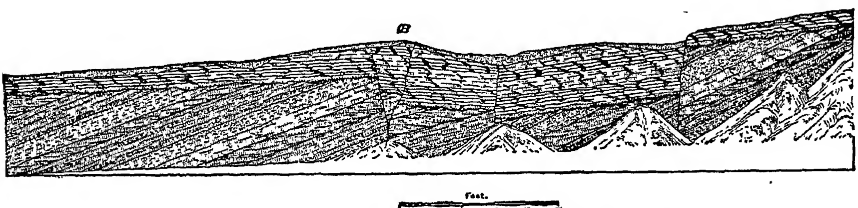


Fig. 546.—Faulting in sediments of Lake Lahontan, Walker River Canyon, Nev. (Russell, U. S. Geol. Surv.)

about the old borders of the lake seem to be almost as perfect as when formed, even the valleys which cross the terraces being small. It is to be remembered, however, that the region is arid and its sediments porous, conditions which do not favor the ready destruction, or even the ready disfiguration, of terraces, deltas, etc. Russell infers that the desiccation of the lake was probably accomplished centuries, but probably not many thousands of years ago.

Recent as the closing stages of Lake Lahontan's history were, there have been considerable diastrophic changes in the region since, for faults affect the lacustrine sediments at various points (Fig. 546). Some of these faults have been traced more than 100 miles, and the throw of some of them is not less than 100 feet, though the amount is usually less. The recent fault movements seem to have been mainly along the lines of earlier faulting (Fig. 547). It is worthy of note that the numerous hot springs of the region are mostly along the lines of recent faulting. This has led to the inference that the friction of faulting was the source of the heat, but this is clearly not the only interpretation possible.

FIG. 547.—Map showing the area of Lake Lahontan and the residual lakes of the present time. The black lines with hachures represent the lines of post-Pleistocene faulting. Most of them were also lines of pre-Quaternary faulting, and some of the latter, indicated by black lines, do not represent sites of post-Pleistocene displacement. The black dots represent springs, many of which are hot. Their proximity to faults is in some cases striking.

Mono Lake.—A lake which occupied a part of Mono Valley, California,[1] had a similar history. The two stages of high water here are associated with two separate advances of the ice. Glaciers descended into its basin below the level subsequently reached by the water. As in the case of the larger lakes farther east, there has been faulting, deformation of the beach lines, and volcanic action in the basin of the lake, since the last retreat of the ice. Mono Lake seems to have been without life throughout most of its history.

There were numerous other Pleistocene lakes in the Basin and mountain regions, but their histories have not been worked out in detail.

Glacial effects.—The extent of glaciation in the western mountains has been outlined in the early part of this chapter. Throughout the area glaciated, there is evidence that the erosive work of the ice was great. This is shown both by the extensive deposits of glacial and fluvio-glacial origin, and by the forms of the valleys occupied by the ice. At the east base of the Park Range in Colorado, for example, there are said to be terminal moraines 1000 feet high.[2] In the Uinta Mountains, the terminal moraines are much less massive, but lateral moraines 1000 feet high[3] are found. Under the conditions of active drainage which existed in the mountains, much of the glacial debris was carried beyond the ice by the water emanating from it, and deposited in the valleys and "parks," or on the plains below. Nowhere in the world where accurate topographic maps have been made, are glacial cirques, the result of a peculiar phase of glacier erosion, better developed than in these mountains.[4]

The characteristics of the mountain valleys which were occupied by considerable glaciers, are essentially constant. They include (1) well developed cirques at the heads (Fig. 548 and Pl. XIX, Vol. I); (2) the upper parts of the valleys, often for some distance below the cirques, are so thoroughly cleaned out, that little loose debris, except that due to post-glacial weathering, remains; (3) numerous tributary valleys are hanging (Fig. 262, p. 290, Vol. I), and their waters form cataracts (Fig. 263, p. 291, Vol. I); (4) at and near the limits of the

[1] The Pleistocene History of Mono Valley, Russell, 8th Ann. Rept. U. S. Geol. Surv.

[2] King, op. cit., p. 468.

[3] This means that the drift is 1000 feet deep. The crests of the lateral moraines are locally 2500 feet above the valley bottoms.

[4] See Hayden Peak and Gilbert Peak, Utah, topographic sheets of the U. S. Geol. Surv., for fine examples of large cirques.

ice, at any stage when its end or edges remained nearly constant in position for a time, there are heavy accumulations of drift, lateral moraines often being more conspicuous than terminal; (5) the valleys

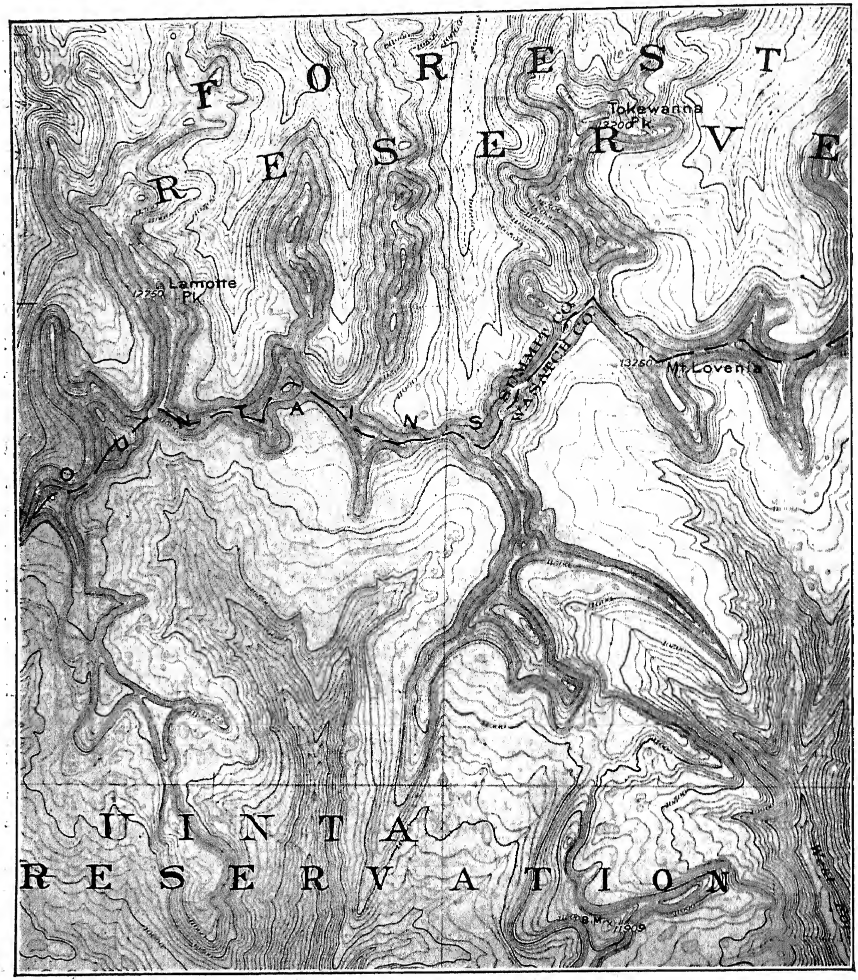


FIG. 548.—Glacial cirques in the Uinta Mountains. (Hayden Peak quadrangle, U. S. Geol. Surv.)

contain lakes (Pl. XIX, Vol. I), some of which occupy rock basins in the cirques, and some occupy basins produced by drift dams in the valleys below the cirques; and (6) valley trains or outwash plains

below the moraines. The partial removal of these deposits has developed terraces (Fig. 551).

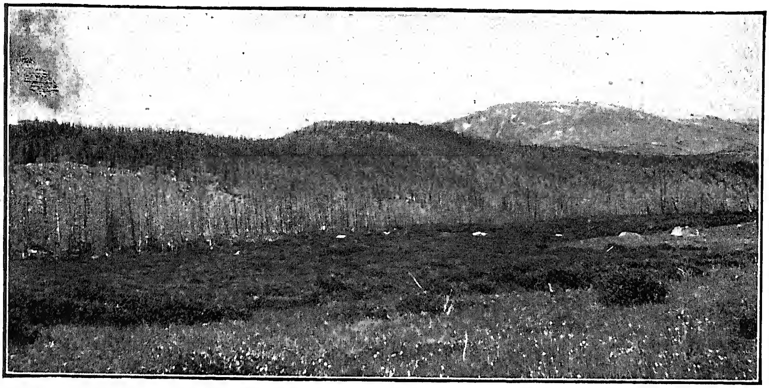


FIG. 549.—Lateral moraine in the valley of the North Fork of Clear Creek, Bighorn Mountains, Wyo. (Blackwelder.) (See also Fig. 278, Vol. I.)

Glacial lake deposits.—By obstructing valleys, the mountain glaciers of the west gave rise to numerous temporary lakes in which extensive

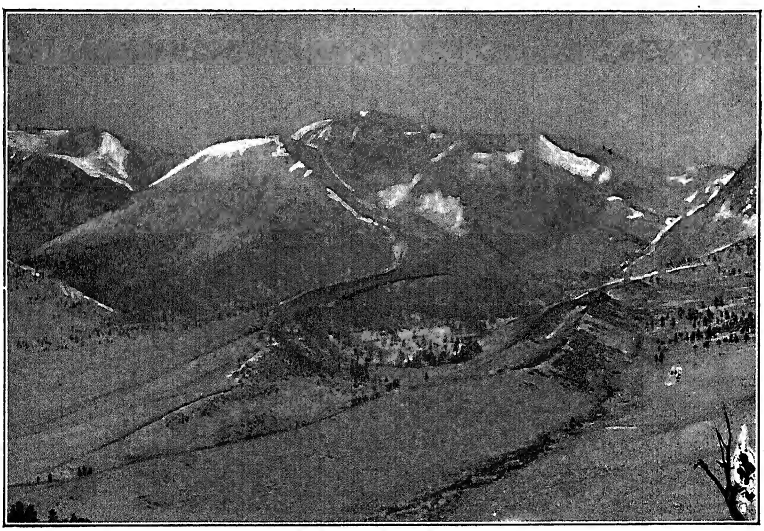


FIG. 550.—The moraines about the lower end of a mountain valley. Bloody Canyon, Cal.

beds of lacustrine sediments were laid down. The extent of such lakes in the west and northwest has not been determined, but where

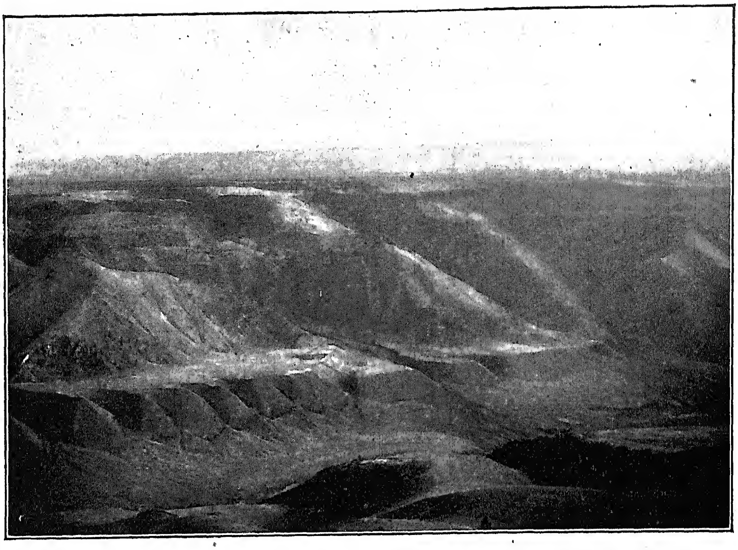


FIG. 551.—Terraces of the Columbia, near Chelan, Wash. The terraces are of glacial gravels. (Atwood.)

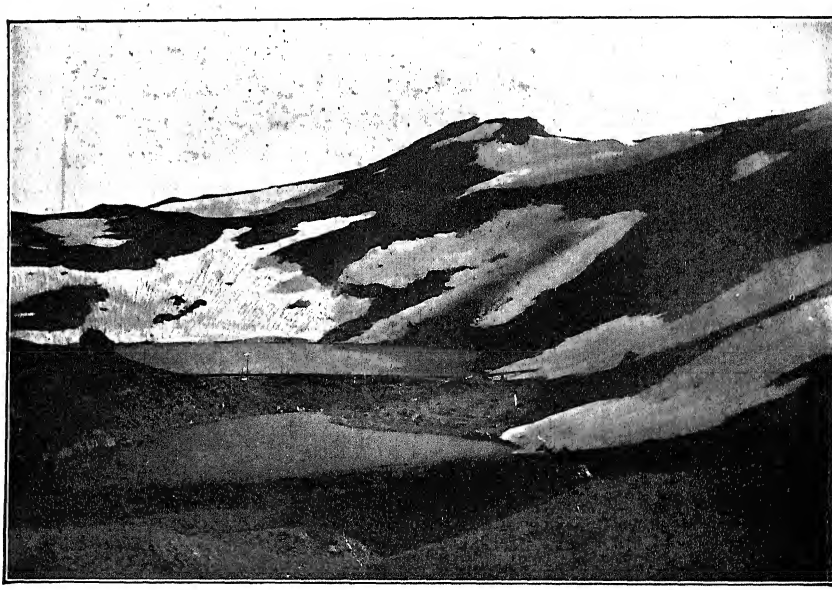


FIG. 552.—Glacial lakes in the upper end of a glacial valley (cirque); near the head of Commodore Gulch. Silverton, Colo., quadrangle. (R. T. Chamberlin.)

glaciation was extensive, derangement of the drainage was common, and deposits of glacio-lacustrine clay, hundreds of feet deep, are known at some points. Where such deposits were made in narrow valleys now drained, they have been partly removed, and their remnants constitute terraces.

Topographic unconformity.[1]—Glaciation in the west was also responsible for a phase of topography worthy of special mention. It is illustrated by Fig. 553. A great glacier passed down through the valley, obliterating the erosion topography of its lower slopes, partly by wearing away the ends of the ridges between the tributary valleys, and partly by filling the lower ends of those valleys, up to the limit of the ice.

FIG. 553.—Topographic unconformity developed by glaciation, and by a glacial lake. Lower end of Lake Chelan, Wash. (Atwood.)

The result was that the well-developed drainage lines on the upper slopes were effaced below, and post-glacial erosion has since developed new channels in this part, continuous with the older ones above, thus giving rise to a *topographic unconformity*. In the case shown in Fig. 553 the lake (Chelan) stood at the levels of the terraces after the ice disappeared, and its shore deposits helped to destroy the lower ends of the preglacial drainage lines. Fig. 551 also shows topographic unconformity.

All evidences point to the conclusion that the glaciation, or at least the latest glaciation, of the western mountains was of very recent date. From a general study of the data at hand, it would appear

[1] Jour. of Geol., Vol. XII, p. 707.

that the last glaciation of the west can hardly have preceded the Wisconsin glacial epoch of the interior. Nevertheless there has been much post-glacial weathering, especially that resulting from the expansion and contraction due to changes in temperature. In favorable localities, this has resulted in the development of enormous bodies of talus, some of which are said to be 1000 feet in thickness.[1] Such accumulations are most extensive in the Sierras.

Alluvial and talus deposits.— In the basin region of Utah and Nevada, there are exceptional deposits of detritus, the accumulation of which was favored by the geographic and climatic conditions. The mountain ranges of the basin region are separated by broad valleys. From the steep slopes, detritus is carried down both by descending torrents and by gravity, and while it is largely deposited at and against the bases of the mountains, some of it is spread widely over the surrounding plains. This débris is mainly unstratified, or poorly stratified, and some of it is very coarse. It occurs in greatest quantity where canyons issue from the mountains, and in such situations huge fans of bowlders, sometimes 1000 feet in height, are found.[2] The torrents were able to carry this coarse material so long as they were confined within the canyons, but with the change of gradient below, the water gave up its load. Where the adjacent mountains are of limestone, the detritus against their bases is often firmly cemented into breccia by lime carbonate. The geographic conditions in the basin region are such as to cause most of the coarser products of erosion from the mountain to be deposited on the lowlands about them. If the Quaternary talus and alluvial deposits were sharply separable from those of late Tertiary age, they would afford a rough measure of the Quaternary erosion in the mountains.

As the glacial deposits increase in importance to the north, talus and other subaërial accumulations become less conspicuous, and are of much less importance in Montana, Idaho, and Washington, than in the more arid regions farther south.

Talus accumulations take on various forms, as shown in Figs. 554 to 556. Fig. 554 shows talus in its normal form. Fig. 555 shows a type of accumulation not uncommon in the western mountains. In some cases at least this disposition of the talus appears to be due to

[1] King, op. cit., p. 472. [2] King, op. cit.

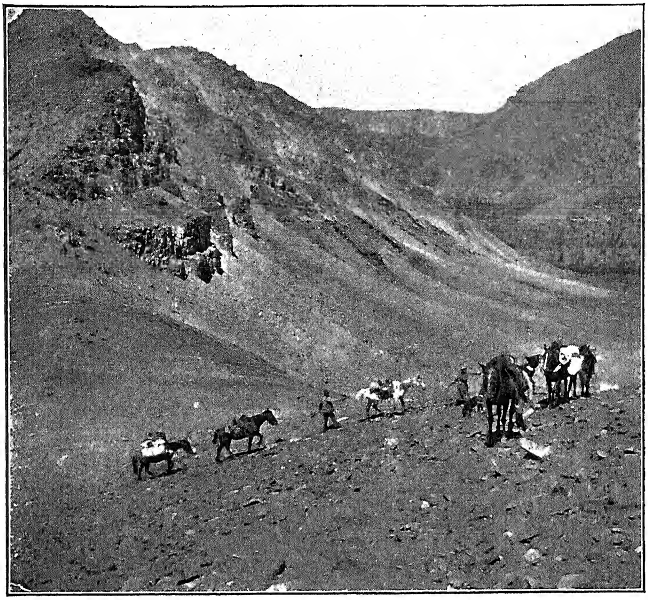


FIG. 554.—Normal steep talus slope.

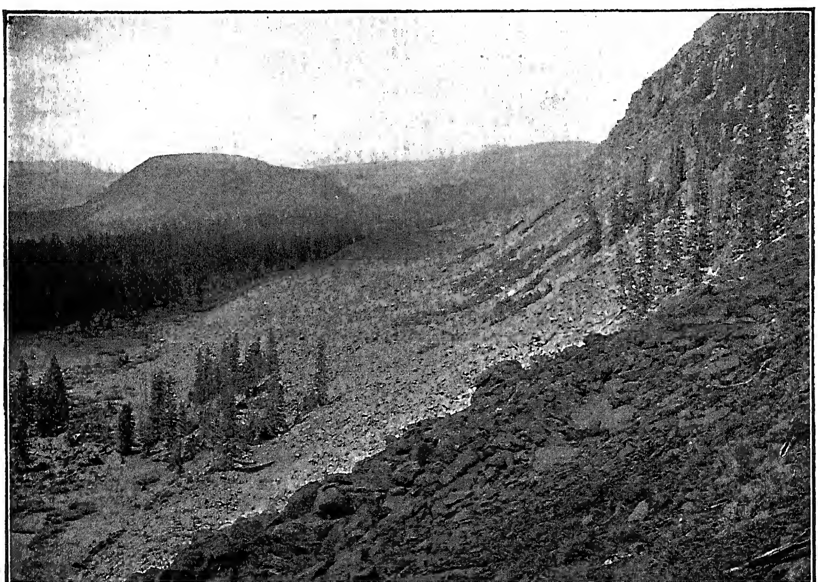


FIG. 555.—Shows the effects of snow-banks at the bases of slopes, on the disposition of talus. White Rocks Creek, Uinta Mountains, Utah. (Church.)

snow banks at the bases of the mountains. The descending talus rolls out over the snow, lodging at its outer edge. It is possible that in some of these cases there is incipient slumping of the talus itself. Fig. 556 shows another type of talus accumulation common in some of the higher mountains of the west. In some cases these bodies of talus have the general outline of a glacier, and have therefore been called "talus glaciers." Their development probably involves several

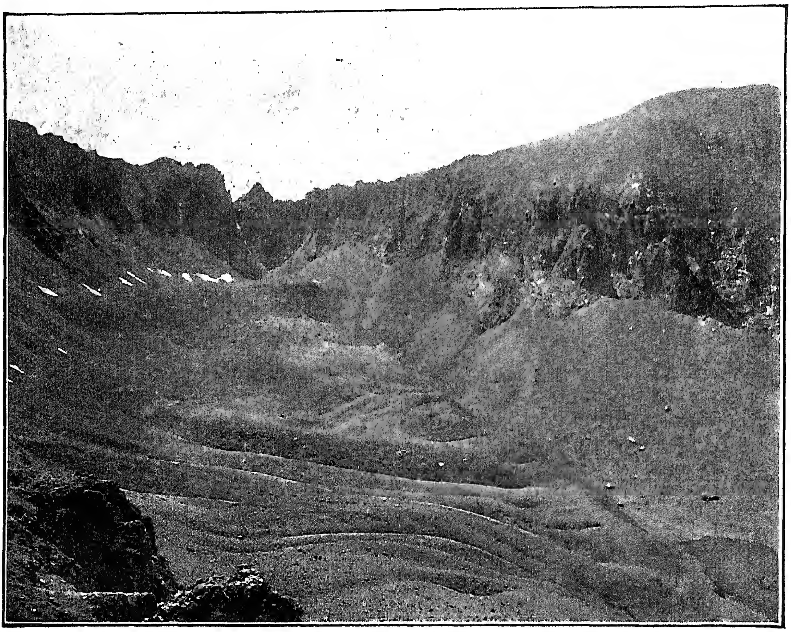


FIG. 556.—An accumulation of talus, where slumping, etc., have been operative. Near Silverton, Colo., at head of Horseshoe basin. (Cross, U. S. Geol. Surv.)

processes besides the descent of loose material down steep slopes. These processes probably include (1) the passage of the talus over snow-banks at the bases of cliffs, (2) sliding, creeping, and slumping of bodies of talus, perhaps both when bound together by ice and when not so cemented, and (3) incipient glacial motion.

All such accumulations now conspicuous in the western mountains are largely or wholly post-glacial, and their development is still in progress.

Eolian deposits.—One of the agencies concerned, both with erosion and deposition, in the western region, is the wind. Its erosive work is shown in the peculiar carving which affects the cliffs and projec-

tions of rock at many points (Fig. 557), and its depositional work by the dunes, which are not rare. The erosive work of the wind is of far greater importance than is commonly appreciated by those unfamiliar with arid regions. Loess apparently of eolian origin, sometimes with volcanic dust interstratified, is wide-spread in some parts of eastern Washington and northeastern Oregon.[1]

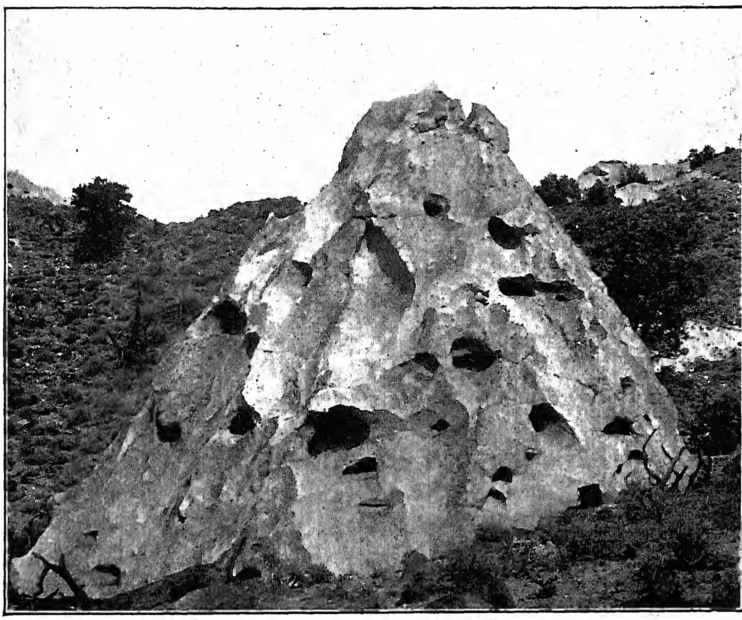


Fig. 557.—Illustrating wind-carving. Palmetto Mountains, Cal. (Turner, U. S. Geol. Surv.)

Deposition from solution.—About many springs, as in the Yellowstone Park, deposits of siliceous sinter and calcareous tufa are now making (Figs. 214–218, Vol. I), and more considerable deposits of the latter material antedate the present by some considerable interval of time. Many of these deposits probably fall within the limits of the Pleistocene period. Their distribution seems to indicate that the sites of deposition have become successively lower and lower, as the valleys have been deepened, the springs taking advantage of successively lower avenues of escape. Tufaceous deposits of the same type are known at various other points in the western mountains.

[1] Salisbury, Jour. of Geol., Vol. IX, p. 730.

Marine deposits.—Along the western coast of the United States there are marine deposits reaching inland some distance from the

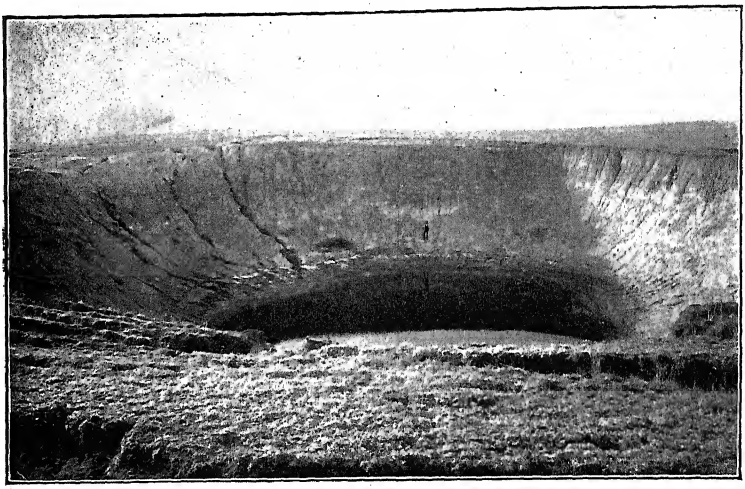


FIG. 558.—A sink-hole of recent development near Meade, Kan. (Johnson, U. S. Geol. Surv.)

coast. They are known to extend up to altitudes of 200 or 300 feet in California[1] and Oregon, and perhaps even higher. The Pleistocene submergence indicated by the disposition of these beds must have

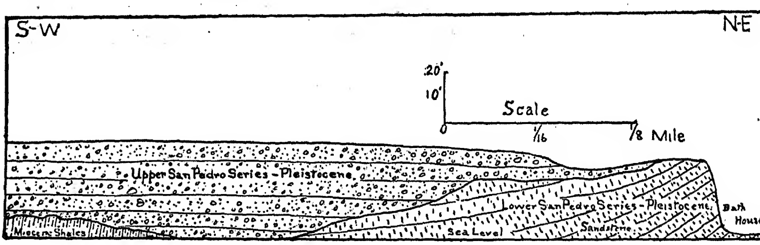


FIG. 559.—An unconformity between Pleistocene formations on the coast of California near Santa Barbara. (Messrs. Arnold.)

given origin to considerable bays in the lower courses of the Columbia and Willamette valleys. In southern California there are two marine Pleistocene formations separated by an unconformity[2] (Fig. 559).

[1] Ashley, Jour. of Geol., Vol. III, pp. 446–50.
[2] The Messrs. Arnold, Jour. of Geol., Vol. X, pp. 117–135.

By far the larger part of the marine Quaternary deposits of the coasts of the continent are still beneath the sea. As interpreted by the marine fossils, the climate of that portion of the Pleistocene in southern California which is represented by these marine stages, was distinctly warmer than that of the Pliocene;[1] but this does not apply, probably, to any large part of either period.

Igneous rocks.—The late Tertiary eruptions of North America have not everywhere been clearly separated from those of the Quaternary period, but there are in numerous places igneous rocks which are clearly post-Tertiary, some of them even late Quaternary. Some of these very young igneous rocks have been referred to in connection with the history of Lakes Bonneville, Lahontan, and Mono, but they are by no means confined to the basins of these lakes. Mount Shasta shows several post-glacial lava-flows,[2] and there are small cinder cones on alluvial cones at the east base of the Sierras in southeastern California.

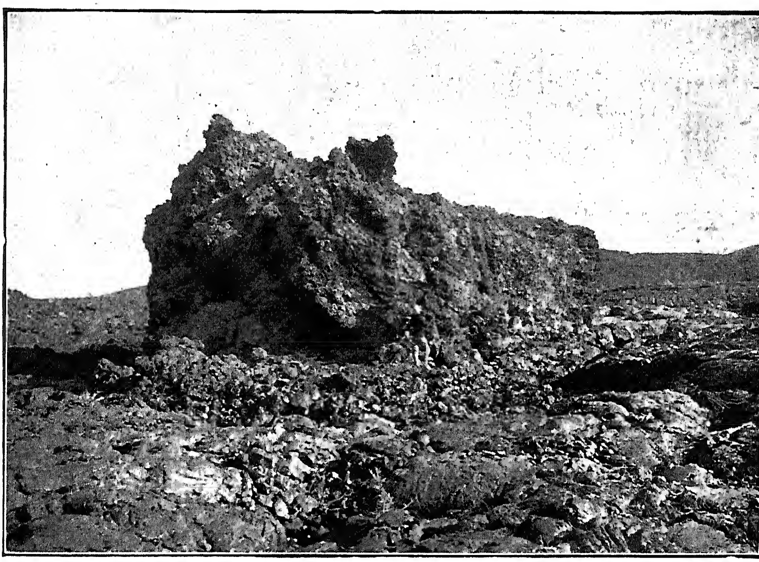


FIG. 560.—A floated crag of scoria, in recent lava-flows, Cinder Buttes, Ida. (Russell, U. S. Geol. Surv.)

[1] Fairbanks, Jour. of Geol., Vol. VI, p. 566.

[2] Diller, Physiography of the United States, pp. 245 et seq.

In other localities, the reference of lavas, tuffs, etc., to this period depends on different criteria. In southern California (Mohave desert)

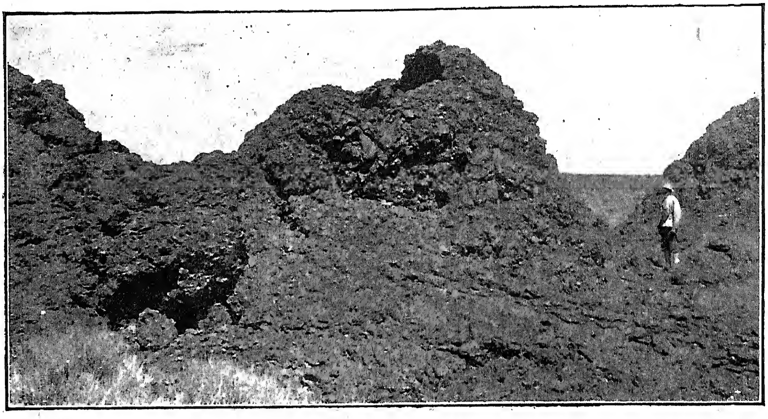


FIG. 561.—Oven of clots of plastic lava. Jordan Craters, Ore. (Russell, U. S. Geol. Surv.)

and northern Arizona (vicinity of Flagstaff), for example, there are cinder cones and lava-flows of limited extent which are so slightly

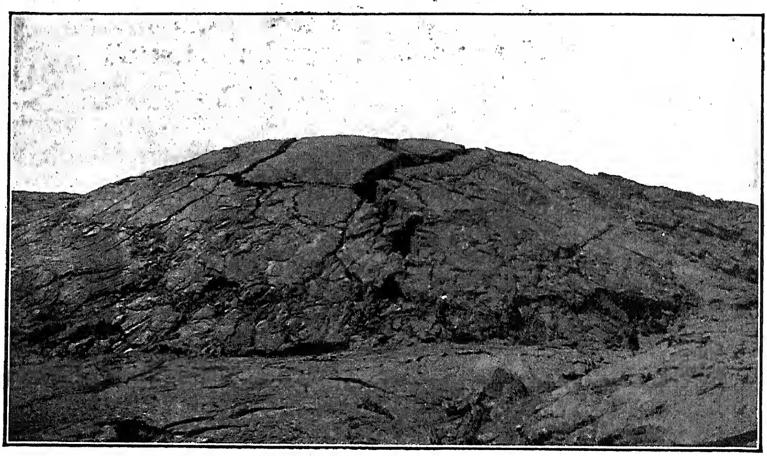


FIG. 562.—Pressure ridge developed in fresh lavas. Jordan Craters, Ore. (Russell, U. S. Geol. Surv.)

touched by erosion that there can be little doubt that they date from a time long subsequent to the beginning of the Quaternary period.

Judged by the same criteria, there are lava-flows and cinder cones of Quaternary age in New Mexico (Fig. 563),[1] Colorado, Utah, Nevada, Oregon (Figs. 561 and 562), Idaho (Fig. 560),[2] Washington,[3] and at various points in the Sierras.[4] On many of them vegetation has hardly begun to gain a foothold. Gilbert estimates that of 250 lava fields observed in these states, 15% are of Pleistocene age, and of 350 volcanic cones in the same states, 60% are considered to be Pleistocene.[5] Volcanic ash is interbedded with loess at various points in eastern

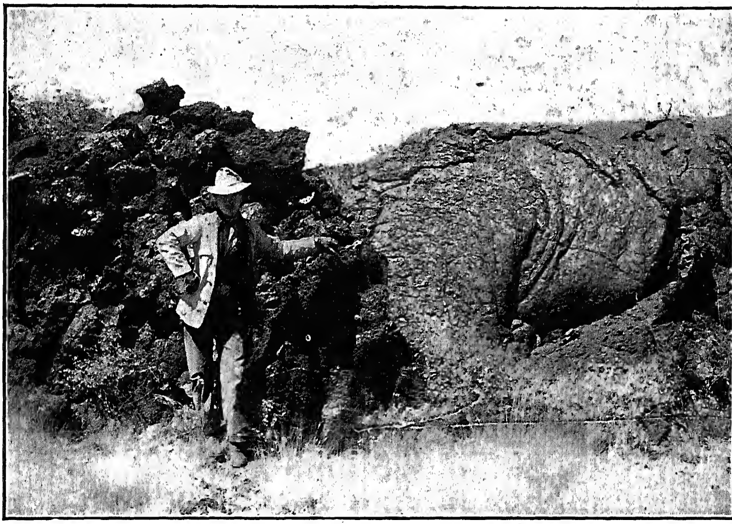


FIG. 563.—Edge of "malpais" (lava), Tularosa Desert, White Oak, N. M. (Hill, U. S. Geol. Surv.)

Washington and Oregon,[6] and overlies glacial moraines in some parts of Alaska. Glacier Peak, Washington, is the remnant of a volcano formed after the base-leveling (Pliocene) of the Cascade Mountain region, and probably after the elevation of the base-leveled tract.[7] Mount Rainier dates from about the same time.

[1] Tarr, Am. Nat., Vol. 25, pp. 524–527, 1891.

[2] Nampa, Ida., folio, U. S. Geol. Surv.; also Russell, Bull. 217, U. S. Geol. Surv.

[3] Tacoma and Ellensburg, Wash., folios, U. S. Geol. Surv.

[4] See Bidwell Bar, Colfax, Downieville, Lassen Peak, Pyramid Peak, and Truckee, Cal., folios, U. S. Geol. Surv.

[5] Mono. I, U. S. Geol. Surv., pp. 323–337.

[6] Jour. of Geol., Vol. IX, p. 730.

[7] Russell, 20th Ann. Rept. U. S. Geol. Surv., Pt. II, p. 134.

Igneous rock has occasionally had a significant influence on modern vegetation, without regard to the age of the lava itself. The unwooded tract shown in Fig. 564 corresponds somewhat accurately with a dike

FIG. 564.—A basic dike, cutting crystalline schists, is the cause of the absence of trees in the central part of the area shown. Bighorn Mountains, southwest of Buffalo, Wyo. (Kümmel.)

of basic rock which affects the crystalline schists of the Bighorn Mountains.

CHANGES OF LEVEL DURING THE PLEISTOCENE.

The very considerable changes of level which marked the closing stages of the Pliocene have been mentioned, and many of them doubtless continued into the Pleistocene.

Certain minor warpings of later date, such as those which affected the basins of Lakes Bonneville and Lahontan during the Pleistocene have also been noted, but such changes are probably but a meager index of the crustal warpings of the period. Specific data on this point are less abundant than could be desired, for the phenomena of erosion and deposition which followed the elevation of the Ozarkian or Sierran epoch are not readily differentiated from the similar phenomena resulting from later elevation. Nevertheless evidence of Pleistocene changes of level, as distinct from late Pliocene, are not wanting, especially near the coasts and about the shores of the Great Lakes. From the evidence at hand, it appears that deformative movements were wide-spread both in the western mountains and in the area covered by

the great ice-sheets. There have also been changes of level, though probably less extensive, in the non-glaciated areas of the southern and southeastern part of the continent.

As already noted, some of the islands of southern California[1] seem to have risen something like 1500 feet since the Pliocene. Other parts of the California coast, and some of the adjacent islands, have been subsiding during the same period.[2] Near San Francisco, the surface is thought to have ranged from 1800 feet below its present level, to 400 feet above.[3] Walcott has estimated that there has been elevation in the Inyo Mountains of California to the extent of 3000 feet during the Pleistocene.[4] Along the northwestern coast of Oregon, it has been estimated that there has been a rise of at least 200 feet during the Pleistocene.[5] Data concerning Pleistocene changes of level in the west are not sufficiently numerous to permit the determination of the axes of movement, if such there be.

In general, the areas covered by the ice of the glacial period have risen since the ice melted. It is a tenable hypothesis that the rise, or some part of it, has resulted from the melting of the ice, and that it followed a depression occasioned by the weight of the ice. The rise of the land has, in general terms, been greatest where the ice was thickest.[6] This rise of the glacial centers is shown in many ways, but especially by the raised beaches along the coast lines, and by the deformed shore lines of the interior lakes. Thus the shore lines of Lake Agassiz[7] are no longer horizontal, but are considerably higher at the north than at the south. Their inclination is as much as a foot to the mile in the northern part of the basin. At the National Boundary, the shore lines are 175 feet above those at the southern terminus of the lake, and 200 miles north of the boundary they are 400 feet above the same point. This deformation was largely accomplished before the lake disappeared.

[1] W. S. T. Smith, Bull. Dept. of Geol., Univ. of Cal., Vol. II. Reviewed in Jour. of Geol., Vol. VIII, p. 780.

[2] Lawson, Bull. Dept. Geol., Univ. of Cal., Vol. I. Reviewed in Jour. Geol., Vol. II, p. 235.

[3] Ashley, Jour. of Geol., Vol. III, p. 449.

[4] Jour. of Geol., Vol. V, p. 340.

[5] Diller, 17th Ann. Rept. U. S. Geol. Surv., Pt. I.

[6] DeGeer, Proc. Boston Soc. Nat. Hist., Vol. XXV, 1892.

[7] Upham, Mono. XXV, U. S. Geol. Surv.

The shore lines of the Great Lakes have been similarly warped. Thus the shore lines of Lake Iroquois,[1] the ancestor of Lake Ontario, decline from the northeast to the southwest at the average rate of three and a half feet per mile, the slope being steeper to the north and gentler to the south. The old shore lines east of the east end of Lake Ontario. are about 400 feet higher than those at the southwest end. The beaches of Lake Algonquin[2] (Fig. 521) are 25 feet above the present lake at Port Huron, and 635 feet above the lake at North Bay, Ontario. The shore lines of the Michigan lobe of Lake Algonquin are 205 feet, above the lake at Mackinac, and are estimated to be 100 feet below the lake at Chicago. Similar figures might be cited for other localities.

The shores of the Nipissing lakes (Fig. 522) show a similar though lesser, deformation. Since the Nipissing lakes were later than the preceding, their shore lines show that the deformation was in progress while the ice was retreating.[3] The import of all these data is the same, namely, that the land or the water surface has been warped since the ice melted, and the change has been greatest toward the centers of glaciation, and that it began before the lakes had attained their present dimensions. A part of the change is undoubtedly due to the effect of the attraction of the ice on the water.[4] This, however, leaves a large residuum to be otherwise explained. The history of many small lakes affords data of the same sort.[5]

Along the Atlantic coast south of the area of glaciation there have perhaps been complex movements, but of no great range, in the Pleistocene period. On the whole, elevation (relative) appears to have exceeded the depression, but the latest movement (present) appears to have been one of depression, as the drowned ends of the valleys between Long Island and Carolina, and numerous other minor

[1] Gilbert, 18th Ann. Rept., U. S. Geol. Surv.

[2] Taylor, A Short History of the Great Lakes, published in "Studies in Indiana Geography"; also Am. Jour. Sci., Vol. LXIX (1895), pp. 69, 249.

[3] Other references relating to post-glacial deformation are the following· Spencer, J. W., Am. Jour. Sci., Vol. XL (1890), p. 443; Vol. XLI (1891), p. 12; Vol. XLII (1891), p. 201; DeGeer, Proc. Bos. Soc. Nat. Hist., Vol. XXV (1892); Upham, Jour. G., Vol. II (1894), p. 383; Taylor, Am. Geol., Vol. XIII (1894), pp. 316 and 365; Am. Jour. Sci., Vol. XLIX (1895), pp. 69, 249; Bull. Am. Jour. Sci., ser. 4, Vol. I, pp. 219, 228, 1896; Coleman, Bull. Geol. Soc. Am., Vol. X (1898), p. 165 et seq.; Fairchild, Bull. Geol. Soc. Am., Vol. X (1898), p. 27 et seq.

[4] Woodward, Bull. 48, U. S. Geol. Surv.

[5] Lake Passaic, Geol. Surv. of N. J., 1893.

phenomena, such as submerged peat bogs, meadows, forests, etc., show.

It is not improbable that movements of equal magnitude have affected the interior regions of the continent, but except about the lakes, there is no datum plane like the sea-level to which these changes may be readily referred. In a few places, notable local deformation is known. In western New York [1] and Ohio, the solution of underlying gypsum and salt is suspected of being the occasion of some of the slight deformations which have been observed.

Foreign.

The salient points in the glacial history of Europe have already been sketched and some indication has been given of the extent of the deployment of ice in other continents. It need only be added here that outside the areas affected by the ice, there are, in all continents, subaërial accumulations of talus, wash, and creep at the bases of mountains, deposits of alluvium in the valleys, and eolian deposits. About the coasts at many points on various continents there are marine sediments ranging from a few feet to hundreds of feet above sea-level. In Europe there are cave deposits regarded as Pleistocene, which are of especial interest because they contain human relics, probably the oldest known. The relics consist of rude stone implements, bones of mammals with human markings on them, and bones of human beings.

The Life of the Pleistocene Period.

Destructive effects of glaciation.—Just as the great ice deployment was the supreme physical event of the Pleistocene period, so the effect of glaciation on the life of the times was the foremost subject of biological importance. It is altogether reasonable to assume that the burial of several million square miles beneath successive mantles of ice, abetted by the southward extension of attendant cold zones and cold currents, wrought great destruction of life, and forced upon what survived no little modification. The logic is so cogent that we must believe it to be true; but several embarrassments attend an attempt to statistically demonstrate the conclusion, and to interpret its precise nature. For concrete proof of the effects, we naturally resort to

[1] Gilbert, Proc. Am. Ass. Adv. of Sci., Vol. XL, p. 249.

a comparison between the pre-glacial life-record and the post-glacial. But the pre-glacial record is wholly a fossil one, subject to the well-known defects of such a record, and subject also to the special forms of destruction that attended the ice invasions. The existing record, on the other hand, is one of immediate and unobstructed observation, and is therefore immeasurably more complete. It follows that many pre-glacial species are found in this very full record that would not appear in a fossil record comparable with that of the pre-glacial time, and hence the number of apparent extinctions of Pliocene species is very much less than would appear if the comparison were made with a post-glacial *fossil* record—such a record of present life, for example, as would be found by geologists some millions of years hence, if it had in the meanwhile been subjected to the usual geological agencies of burial and destruction. Without doubt, multitudes of pre-glacial species yet live that are imminently moribund, and many of these would not be found in a fossil list of the distant future, under usual geologic conditions. It is very difficult to make adequate allowances for this inequality in the records when comparing pre-glacial and post-glacial life, and hence it is difficult to measure, by such a comparison, the destructive effects of the intervening ice invasion.

It is to be noted further that the resilience of life is very rapid, when measured in geologic terms. The excessive possibilities of multiplication of most living creatures give great capacity for recovery from depletions, and as our present census is taken some thousands of years at least after the last notable ice invasion, there has been, without question, great increase of life, especially in the higher latitudes most affected by the glaciation.

An added source of embarrassment in the comparison is the especially disturbing influence of man. This is indeed to be regarded as a geological influence, and to be put in the same category as the influence of other races, as they have risen to dominance; but none the less it qualifies the comparison of life before and after the glacial period, so far as it concerns the destructive effects of the ice invasions.

Of the marine Pliocene invertebrates, more than half the known species are now living, whereas, in the transition between several of the more ancient periods, nearly all species disappeared. Of the Pliocene plant species, a very considerable percentage are still living. On the other hand, the land vertebrates were very generally replaced by

new species or became extinct. The same appears to have been true of the insects. Interpreted in the light of the above considerations, there seems warrant for the view that the ice invasions wrought a very serious depression in the life of the globe. It is scarcely possible to avoid the conviction that, at the height of glaciation, the sum total of life on the globe was very greatly reduced. It is probable that even the re-expanded life of to-day is appreciably inferior in abundance to that of the middle Tertiary. Our era is probably one of relative impoverishment, and what is perhaps more important, it is probably a period of relatively poor adjustment of life to life, and of life to physical environment. It is improbable that, in the process of recovery of the millions of square miles denuded of life by the ice-sheets, there has yet been worked out the best balance between the vegetative life and the soils and climatic conditions on which it is dependent, between the herbivorous animals and the plants on which they are dependent, and between the carnivorous animals and the herbivores on which they prey, together with all the complicated sub-adjustments that are involved in a well-adjusted peopling of the earth.

To-and-fro migration.—A distinguishing feature of the effects of the ice invasions on the life of the glacial period in northern latitudes was an enforced oscillatory migration in latitude. With every advance of the ice, the whole fauna and flora of the affected region was forced to migrate in front of it, or suffer extinction. The arctic species immediately adjacent to the ice border crowded upon the sub-arctic forms next south of them, the sub-arctic forms crowded upon the cold-temperate forms, and these in turn upon the warm-temperate types, and so on. It is not unlikely that the limits of the tropical zones even were shifted, and the torrid belt appreciably constricted. With the succeeding deglaciation of the interglacial stages, a reversed migration followed. Present evidence seems to warrant the belief that five or six such to-and-fro migrations were experienced in America and Europe, and that the southward and northward swing of these movements was several hundred miles in extent, in some cases perhaps one to two thousand miles. Some of the interglacial epochs saw a northward extension of mild-temperate forms greater than that of to-day, from which it is inferred that the interglacial climates were milder than the present, and hence that the ice-sheets were at least as much reduced as now. There is in this also ground for the inference that the northern tracts

were at least as extensively peopled by plants and animals as they are to-day. This carries the conclusion that the migratory swing in these more pronounced cases was at least 2000 miles in North America, and more than 1000 miles in Europe. As indicated in the physical description, the geological evidences drawn from erosion, weathering, and organic accumulation warrant the belief that the interglacial intervals were long enough to permit a complete northern return, and the fossil evidence supports the conclusion that the climates were congenial enough to invite it.

The forced migrations must, in their nature, have been peculiarly effective in bringing to bear a severe struggle for existence, and in calling into play the full resources of the plastic adaptation of the life. Forms previously specialized to meet local conditions were put to a most adverse test, for the invading ice forced every form within the glaciated area to move on, while the fringing zones of depressed temperature encircling each ice-sheet, forced plant and animal life, even beyond the ice border, to seek new fields and new relations, both physical and organic. An incidental result of this wholesale migration was an unwonted commingling of plants and animals, for every aggressive form pushed forward in the van of the advancing zone, and hence came into new organic environment, while every laggard form fell behind, and was overtaken by the less reluctant migrants.

Definite climatic zones.—From the nature of the case, and from the evidence, it appears that not only must sharply defined climatic zones have surrounded the invading ice-sheets, but that these must have been much more strongly distinguished from one another in temperature than had previously been the case since the Permian times. As these diverse zones were alternately pushed forward and withdrawn by the advances and retreats of the ice, every organism was forced by a special stress, either to adapt itself to a new zone, to migrate, or to suffer extinction.

Climatic adaptations.—Two or three notable results appear to have followed. Certain forms became more highly adapted to special climatic zones than they had been previously. It has been remarked before that the floras of the middle Tertiary were highly mixed, judged by the present climatic adaptations of the species. Types which we now regard as tropical were living in high latitudes, commingled with forms which are now boreal. So also forms that are now boreal were

then living in low latitudes, with forms now tropical. The sifting influences of the to-and-fro movement of the sharply differentiated climatic zones, seem to have sorted out the mixed assemblage, or to have forced them into special adaptations, or both, so that to-day most species are confined to definite climatic zones. This was not universal, however. Certain forms seem to have met the stress of the times by becoming adapted to various climatic conditions. This versatility of adaptation finds its highest expression in man, but in this case it is secured by extraneous means not available to the lower creatures. Seasonal oscillations are met by birds and certain other animals by seasonal migration. The cases of versatile adaptation are, however, quite inferior in number to those adapted to limited climatic zones only.

Superposition of cold and warm faunas and floras in the record.—The to-and-fro movement of the faunas and floras introduced into the record exceptional superpositions of faunas upon one another. The succession was orderly but unusual. Where a complete record could be made, as in a depositing tract just outside the limit of the invading ice, the full series for the advancing stages of an ice invasion should embrace a succession of faunas and floras ranging from the temperate, through cold-temperate and sub-arctic, to the extreme arctic types, while a full record of the retreating stages of the ice should embrace the same series reversed. Such an orderly superposition should ideally be repeated as often as there were ice invasions of the requisite magnitude. In every interglacial period, therefore, there should be embraced ideally a series of forms ranging from the arctic to the most temperate compatible with the interglacial conditions, and thence backward to the arctic. It is important to observe this range in interpreting the fossils of interglacial deposits, for the presence of arctic and subarctic faunas and floras in the lowermost and uppermost portions of an interglacial series does not necessarily preclude the occurrence of temperate forms in its middle part. Care in observing the exact horizons from which fossils come is obviously required to avoid mingling distinct groups. It is obvious so delicate and so changeable a record would only be perfectly preserved under exceptionally favorable conditions. No series having such ideal completeness has yet been described, but series embracing sufficient representatives of cold and warm climates are known to justify this ideal conception, and to make it the working basis of observation, record, and interpretation.

Mixing of relics.—Not only was such an ideal symmetry in the succession of faunas and floras too delicate to be often perfectly preserved, but it was easily subject to mutilation and mixture. Relics which were deposited in the first stages of retreat were liable to be washed out by the succeeding drainage and commingled with the deposits of a later stage. So also, as these interglacial beds were loose deposits and more or less exposed at the surface, they were subject, at various later times, to various kinds of disturbance, as by the burrowing of animals, the overturning of trees, the filling of root-holes, and the various incidental disturbances which affect loose superficial deposits. There were also normal shiftings of fluvial material, the reworking of river-bottoms and terraces, the cutting and filling of gullies, the creeping and sliding on declivities, the inevitable slope-wash, and similar surface disturbances. Unusual circumspection is therefore requisite in observing and interpreting the life relics found in this class of deposits.

Real intermingling of northern and southern species.—Besides the post-depositional mixing of forms that were originally separate, there was undoubtedly a true intermingling of northern and southern species while living, for the migrations could not well keep even pace with the climatic variations. Plants necessarily lingered until the invading climate destroyed them. The *species* migrated by the accidental transportation of their seeds, but the *individual plants* had no such power of migration, and they, and the offspring of such seed as they planted beneath and about them, remained until destroyed. Under these conditions, the advance forms of each shifting zone must inevitably have overtaken and mingled with the lingering forms of the adjacent zone, and these must have been subject to burial and fossilization together. This also serves to perplex interpretation.

Even in the case of animal species whose facilities for migration are freer, the literature of the subject contains puzzling statements of strange associations. In the caves of Britain, the relics of the arctic musk-ox are said to be found closely associated with those of the hippopotamus; in the caves of France, the relics of the reindeer with those of the lion; in the caves of Belgium, the auroch and the Alpine chamois with the sub-tropical hyena.

Cave deposits.—A special phase of record, and also of the mixing of relics, is found in the cave deposits of the period. Caves were undoubtedly the resorts of land animals in the Tertiary and earlier periods,

but as caves are rather transient features, subject to early obliteration, they and their contents are rarely preserved in the record of the more ancient periods. Those which were formed so late as the Pleistocene period, however, have frequently endured, and have become the receptacles of valuable relics. The cave earth and the stalagmite that accumulated on the bottoms of the caves enveloped and retained animal relics more often than most superficial deposits, for the obvious reason that the caves were not only frequented by many predaceous animals, but were the depository of the inedible relics of the prey these animals dragged into their retreats. So long as the bottoms of the caves were occupied by cave earth only, this was liable to be dug over by the fossorial forms of the cave-frequenting animals, and the relics of different stages mixed. When, however, the earth was periodically covered by a floor of stalagmite, mixture was restricted to the intervening stages, and the inter-stalagmite relics recorded the order of occupancy with measurable fidelity. Cave deposits are chiefly limited to non-glacial regions, and to those glaciated regions where erosion did not cut them away or the deep drift bury them beyond reach. Fissures, as well as sinks and caverns, occasionally preserved the relics of animals that fell or were washed into them from above. In these cases, the order of burial is usually subject to some doubt owing to irregularities in the mode of filling; but in some cases the succession is fairly certain. In such cases, however, the known order of the life succession is usually more depended upon to determine the age of the several portions of the deposits, than is the order of the deposits to fix the age of the life.

Existing alpine remnants of the migrations.—Significant evidence of the northerly and southerly migrations of the glacial period is found recorded in the present life of the higher mountains within or near the borders of the once glaciated areas. It is obvious that at the time the ice stood in the vicinity of these mountains, the only life which could occupy them, if any at all, was of the arctic type. As the ice retired to the north, the arctic life of the surrounding lowlands moved northward after it, and the temperate life came on to take its place. Upon the mountain sides and summits, however, the arctic life still found congenial conditions; but it was compelled to ascend to higher and higher altitudes as the warmer climates advanced. It was thus soon cut off from the retreating arctic life of the lowlands,

and became at length thoroughly isolated on the upper zones of the mountains. On the summits of the higher peaks, such life still finds suitable conditions, and stands as a living record of the former life of the zone bordering the ice-sheet and surrounding the mountain base. On the heights of some of the Appalachians, of Mount Washington, and of similar peaks, arctic plants, insects, and small mammals, whose kin now live in the arctic zone, remain to this day.

Life of the Interglacial Stages.

For obvious reasons very little is known of the life of the glacial stages themselves, except as it is inferred from fossils found in regions outside the territory invaded by the ice. The precise succession in these regions, in America at least, has not yet been so closely correlated with the several glacial stages as to make conclusions wholly safe. The general relations of life to the adjacent ice invasions are determinable; but as yet no systematic series corresponding in number of divisions to the glacial stages has been found in orderly superposition, and bearing the physical connections, or the fossils, necessary for satisfactory correlation. The glacial waters were sterile, silty, and cold, and hence not many fossils have been recovered from their deposits at points where they are so intimately connected with the ice deposits as to fix their time relations with certainty. It follows that by far the larger part of the fossils whose exact relations to the ice invasions can be fixed, are those which are found in the interglacial beds. These, therefore, possess the highest order of value. But even here no little circumspection is necessary to make sure that the fossils were originally deposited contemporaneously with the interglacial formations, and not introduced into them from earlier deposits by ice action or interglacial wash.

The Toronto beds.—By far the most instructive interglacial beds thus far carefully studied in America are those on the Don River and in the Scarboro cliffs, near Toronto, Ontario.[1] The fossil-bearing

[1] Coleman, Interglacial Fossils from the Don Valley, Toronto, Am. Geol., Vol. XII, 1894, pp. 86–95, with references to earlier literature, including Hinde's important initial work; also Glacial and Interglacial Beds Near Toronto, Jour. Geol., Vol. IX, 1901, pp. 285–310. Coleman and Penhallow, Canadian Pleistocene Flora and Fauna, Rep. Com. Brit. Assoc., Bradford Meeting, 1900, pp. 328–339. Penhallow, Notes on Tertiary Plants, Trans. Roy. Soc. Ca., Vol. X, 1904, pp. 56–76.

beds are underlain by a sheet of bowlder clay which has not yet been positively correlated with its contemporary sheet in the series previously described. It can only be said that it is the equivalent of one of the older drift sheets. The Iowan has been suggested, but it may perhaps equally as well be correlated with an earlier stage. This basal sheet of till is succeeded by a horizon of erosion; and this, in turn, by interglacial beds of stratified sand and clay reaching a maximum thickness of more than 150 feet, the lower portion of which constitutes the Don formation, and the upper portion, the Scarboro formation. Above the latter is another horizon of erosion, which, in turn, is surmounted by sheets of bowlder clay and assorted drift, together attaining a maximum thickness of 200 feet, and referred to the Wisconsin stages.

Recalling the ideal succession of faunas and floras of a typical interglacial epoch, viz.: (1) arctic, (2) cold-temperate, (3) warm-temperate, (4) cold-temperate, and (5) arctic, it is to be observed that in the Toronto series the arctic and cold-temperate faunas, which should theoretically have followed the retreat of the earlier ice, and should have been recorded in order above the basal bowlder clay, have not been identified. Their places are perhaps represented by the erosion horizon between the basal bowlder clay, and the stratified sands and clays of the Don formation.

The latter formation contains a warm-climate fauna and flora, and is, therefore, assignable theoretically to the mild middle part of the interglacial epoch. Up to 1900, the flora of this stage had yielded to the industry of Coleman and others 38 species of plants distributed through 26 genera, as identified by Penhallow. Many of these species indicate a climate appreciably warmer than that of Toronto at present. Among these are the pawpaw, (*Asiminia triloba*) and the osage orange (*Maclura arantiaca*), which now flourish only in more southerly latitudes. The maple, elm, ash, oak, hickory, basswood, etc., were present, suggesting that this region was then forested with trees of types which now flourish typically farther south. The whole group, according to Penhallow, implies about such a climate as now prevails in the middle United States, in latitudes 3° to 5° farther south.

The fauna of this stage contains about 40 species of mollusks, several undetermined species of beetles and cyprids, an undetermined fish, and possibly a mammoth or mastodon, and a bison. Among the

mollusks, 11 species were unios, of which 4 are now living in Lake Ontario, 3 are now living in Lake Erie, but are not recorded from Lake Ontario, and 4 are not known in the St. Lawrence waters, but are now living farther south in the Mississippi basin.

All these plants and animals had undoubtedly been driven entirely out of the St. Lawrence basin by the previous ice invasion. The interglacial interval must therefore have been long enough for a varied fauna, containing many clams and other mollusks, and a complex flora containing many forest trees, to migrate through at least several degrees of latitude. This gives some suggestion of the importance of the interval marked by the erosion horizon below the Don beds.

Above the warm-climate fauna and flora of the Don beds, there is a cold-climate fauna and flora in the Scarboro beds, embracing 14 species of plants and 78 species of animals, 72 of the latter being beetles. This assemblage implies a cold-temperate climate of about the type which now prevails in the region just north of Lake Superior, or that of southern Labrador. The arctic fauna and flora, which should theoretically have followed this cold-temperate one, heralding the immediate approach of the next glacial invasion, is undiscovered. It is probably unrecorded, its time-place falling within the long period of erosion that intervened between the deposit of the Scarboro beds and the formation of the overlying glacial bowlder clay.

Of the complete ideal series (arctic, cold-temperate, warm-temperate, cold-temperate, and arctic), the third and fourth are well recorded, while the rest are probably missing because they fell within the erosion intervals. The later of these intervals, judged by the amount of erosion accomplished, and by the changes of attitude or the cutting down of the basin rim necessary to inaugurate and perpetuate the erosion, are such as to indicate an interval as long as the whole post-glacial epoch. It was therefore quite ample to account for the non-appearance of the later or advancing arctic fauna and flora. The horizon of earlier erosion is less well recorded physically, but if it covers the time of the retreating arctic and cold-temperate faunas and floras, it, too, was doubtless important.

It is obvious that the record implies a pronounced migratory oscillation, but the full measure of this oscillation cannot at present be very closely approximated. The record merely shows that the pawpaw, osage orange, and their mild-temperate associates flourished in

marine life of the cold northeastern coast was, at the close of the Champlain, merging into the existing forms, and these were shifting northward into their present habitat.

Marine life on the more southerly coasts.—Away from the immediate influences of the ice-sheets, the record of marine life does not indicate any profound departure from the progressive modernization that had been in progress through the Tertiary period. It has been remarked by Dall that the Pleistocene fauna on the Atlantic coast does not imply as cold waters as did the Oligocene fauna, and by Arnold that the Pleistocene fauna of the California coast does not imply as cool a climate as does the Pliocene fauna of that coast. It is to be noted, however, that the known marine record does not presumably cover more than a small part of the Pleistocene period, and that it is not at all certain, or perhaps even probable, that the portion represented was any one of the glacial epochs. When the ice was pushing into the ocean on the coast of Maine, as in the Late Wisconsin epoch, and an arctic fauna occupied that coast, it is scarcely probable that a warm-temperate fauna lived on the southern coast; nor is it probable that, when all the inlets of the coast of British Columbia, from Juan de Fuca northward, were shedding icebergs into the Pacific, a warm-temperate fauna lived along the California coast; but warm-temperate faunas on those coasts are entirely consistent with such interglacial climates as are represented by the Don beds, and they might also have been quite consistent with the conditions that prevailed just before or just after the glacial stages. These last fall within the broader limits of the Pleistocene period, as it is usually defined in the marine series. These limits probably do not correspond very closely with the glacial limits which are usually adopted for the land series, wherever glaciation prevailed.

The Terrestrial Life of the Non-glacial Regions.

As previously indicated, the land life of the regions distant from the glaciated areas cannot at present be correlated closely with the glacial and interglacial stages, and must be treated more generally. One of its most marked features consisted of a northern group of indigenous and Eurasian origin, that appears to have been driven far south during the stages of ice advance, and to have followed the retreat-

ing ice well to the northward in the intervening stages of deglaciation. Whether there was intermigration with Eurasia by the northeastern or northwestern routes during the interglacial intervals, is not positively determined, but it is not improbable. The great proboscidians, the mammoth and mastodon, and the bear, bison, reindeer, and musk-ox, were characteristic members of this group. With these, in the mid-latitudes, were mingled several types on the verge of extinction in North America, such as the horse, tapir, llama, and sabre-tooth cat.

A second prominent feature was a southern group consisting of gigantic sloths, armadillos, and water-hogs, whose forebears had come from South America when the isthmian route had been opened in the Pliocene. There is perhaps room for question whether these southern giants ever lived in the mid-latitudes after the first ice invasion, though remains referred to the Pleistocene have been found as far north as Pennsylvania and Oregon. If these really fall within the glacial period proper, there must have been a northern migration in some one or more of the mild interglacial epochs.

The boreal group.—As in the Pliocene, the proboscidians dominated the fields and forests in mid-latitudes. A leading form was the mammoth (*Elephas primigenius* or *columbi*) which ranged from the southern states and Mexico northward probably to a fluctuating line determined by the stages of glaciation. In interglacial stages, and at the close of the glacial period, it seems to have ranged far to the north, for remains have been found in Canada and Alaska. Siberian species which have been kept in cold storage in underground ice or frozen earth, show that the mammoth, there at least, was covered with wool and hair and was obviously adapted to a cold climate. It is not improbable that the southward range to Mexico represents the mammoth's exceptional migration in front of the ice invasions rather than a permanent occupancy of such low latitudes, for the mammoth is said to have been limited in its southerly range in Europe. The *Elephas* survived the glacial period in America, and its tusks and skeletons are not infrequently found in beds of peat and muck that have accumulated in the shallow basins on the surface of the late Wisconsin drift, in the northern United States and Canada, indicating its presence there some time after the ice left the country finally.

The mastodon also ranged widely over the Northern States and into Canada, as well as southward into the Southern States. Not

improbably its range also was shifted with the glacial movements; but as it emigrated to South America and crossed the tropics, it cannot have been ill-adapted to a warm climate, as perhaps the mammoth was. The mastodon likewise lived through the glacial period, and is found in post-glacial deposits in middle latitudes. Williston is authority for the suggestive fact that, while mammoths were very

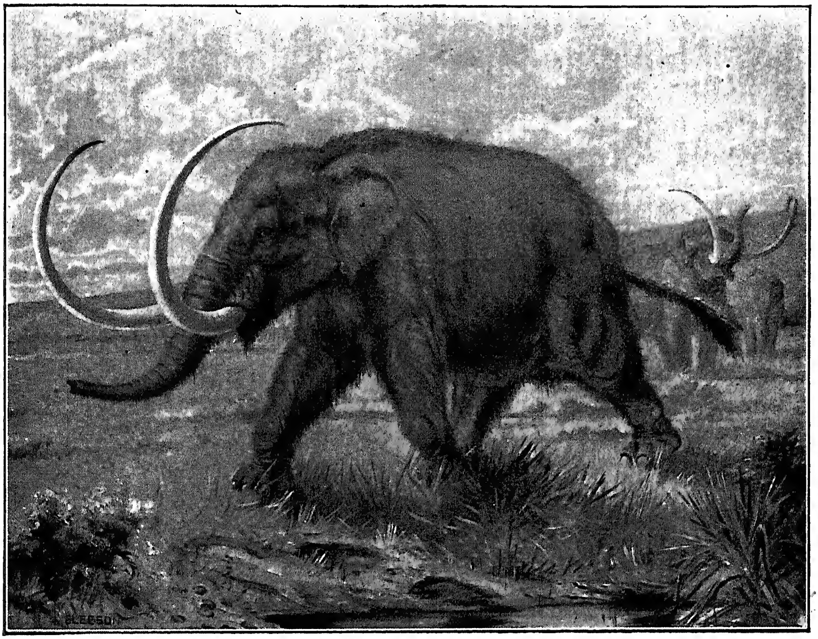


FIG. 565.—An interpretation of *Mastodon americanus* by G. M. Gleeson. (From painting in National Museum, Washington.)

abundant in Kansas and in the open plains where forests seem not to have prevailed in Pleistocene times, the mastodon was almost exclusively confined to the valleys and timbered regions, notably those of the Eastern States, the Mississippi valley, and the foot-hills and shores of the Pacific Coast. The mastodon has never been found on the plains of Kansas, and the mammoth seldom in the formerly wooded valleys. This calls in question the prevalent view that the presence of the mammoth necessarily implied arboreous vegetation. Arboreous vegetation, however,—of the minor type at least,—was present as far west as Iowa and Dakota in some of the interglacial intervals.

Several species of horses have been found in western beds referred to the Pleistocene period. A gigantic elk ranged from Mississippi at least as far northeast as New York, and in the interior as far north as Kansas. Two or three species of buffaloes roamed over the Ohio valley, and southward to the Gulf. The musk-ox (*Ovibos*), a thoroughly arctic animal, now living on the very borders of the ice-fields, has been found as far south as Virginia and Kentucky, as has also the reindeer. A large saber-toothed cat mingled its remains with those of *Elephas* in Oklahoma. The beaver-like *Casteroides ohioensis* is known to have ranged from Ohio and New York, south to Mississippi. Bears, rather recent emigrants from Eurasia, were present, as were also wolves, peccaries, and the vanishing group mentioned above.

The southern group.—Over against this assemblage of more or less boreal forms that were pushed southward by glacial advances, there was the group of South American immigrants, the monster sloths, *Megatherium, Mylodon, Megalonyx,* and the gigantic armadillo, *Glyptodon*, the last covered by a strong carapace of sculptured ossicles, and armed with a massive tail plated with spiked ossicles. The remains of this group have been found chiefly in caverns and crevices, or in the muck and mire about salt springs, or in fluvial deposits, the precise ages of which are difficult to fix, and it ought not to be very firmly concluded that they were present during the glacial period, until their remains are found in interglacial beds, or in demonstrable equivalents of the glacial series. There is apparently nothing, however, in the climatic conditions of such an interglacial stage as that which permitted pawpaws and osage oranges to flourish about Toronto, to forbid their presence in the most northerly ranges in which their relics are found, Pennsylvania and Oregon. Whether they could have held their ground in North America when the ice-sheet reached southern Illinois, is more problematical.

The European Pleistocene Life.

Oscillatory migrations.—A complete agreement as to the migrations of faunas and floras in Europe during the glacial period is yet to be reached, but the data have been sufficiently developed to justify the tentative attempts that have been made to trace the oscillations

in detail. The following outline is borrowed essentially from the writings of James Geikie.[1]

The earliest indications of an approaching ice age are met with in the marine deposits of the late Pliocene period. The earlier Pleistocene life indicates genial climatic conditions, but toward the close of this initial stage, marine forms adapted to mild temperatures retreated from the North Sea, while boreal types came to occupy their place. Similar migrations affected regions farther south, and many boreal forms found their way into the Mediterranean. On the land, like changes took place, and the luxuriant flora and the great mammals of the Pliocene retreated before the advancing glacial climate.

During the first glacial epoch, a thoroughly arctic fauna lived in the North Sea, while during the first recognized interglacial epoch following, the arctic fauna retreated from the North Sea. On the land, during this interglacial interval, a temperate flora, comparable to that now existing in England, clothed the British Isles, while the hippopotamus, elephant, deer, and other mammals invaded Britain by way of the land bridge which then connected it with the continent. A similar flora and fauna advanced to corresponding latitudes on the mainland. A luxuriant deciduous flora occupied the valleys of the Alps and flourished at heights which it no longer attains. Toward the close of this interglacial epoch, the temperate flora retired, and an arctic flora gradually took its place.

During the second glacial epoch, according to Geikie, the ice reached its maximum extent in Europe, and arctic-alpine plants occupied the low grounds of central Europe, while northern mammals, embracing the reindeer, the arctic fox, and the arctic glutton reached the mountain ranges of southern Europe, and even the shores of the Mediterranean.

During the second interglacial epoch, the arctic-alpine flora and the northern fauna retreated over the lowlands of central Europe, and were replaced by temperate and southern forms. The plants which then occupied northern Germany and central Russia imply a milder climate than the present, and the mammalian fauna, which included the hippopotamus and elephant (*Elephas antiquus*), was in keeping with the flora. Toward the close of this interglacial epoch, however, a northern facies began to be assumed, and as the third gla-

[1] The Great Ice Age, Third Edition, pp. 607–615.

cial epoch came on, the northern types were pressed well to the south, but not to the extreme extent of the preceding epoch.

The deposits of the third interglacial epoch embrace, in some places, temperate marine faunas, and in others arctic forms. The mammalian fauna embraced the Irish deer, the horse, the mammoth, and the woolly rhinoceros. The evidence favors the belief that the climate became ameliorated to a degree congenial to a cool-temperate fauna, but not to a warm-temperate or subtropical fauna.

During the remaining epochs, the oscillations were apparently much less wide, ranging between cold-temperate and sub-arctic in northern and middle Europe; in short, the to-and-fro migrations of the life appear to have died away in oscillations of decreasing amplitude, corresponding to the subsiding oscillations of the glacial stages.

The Pleistocene Life of the Southern Hemisphere.

Life in South America.—While the Pleistocene life of North America and Europe bore a close similarity to one another, that of South America had a character quite its own. The major fauna was composed of two great elements, (1) the gigantic sloths and armadillos, which were indigenous to that country, and (2) the descendants of the Pliocene mammals which had migrated from North America. It is possible, on the other hand, that a portion of the extinct South American fauna, referred to the Pleistocene, really belonged to the late Pliocene. The indigenous element of the fauna was rendered remarkable by the abundance and extraordinary dimensions of the great extinct sloths and armadillos. Among the northern immigrants were horses, mastodons, llamas, tapirs, wolves, and a large variety of rodents. The gigantic character and seeming great abundance of the fauna, taken as a whole, and especially that of the edentates, seems out of harmony with the repressive conditions which might reasonably be inferred from the crowding of the faunas toward the tropics by the advance of the glacial climates from the higher latitudes, and by its development on the mountains and plateaus. It might naturally be anticipated that there would result a sharp struggle for existence, attended by the destruction of the least adapted forms and the numerical reduction of the whole. Just such a reduction has taken place since, if not then, and this seems to give some force to the suggestion that the

luxuriance of this great fauna really antedated the congestion attendant on the maximum extension of the ice, and that the extinction of the giant edentates, which seems to have followed their abundance somewhat closely, was connected with this extension. If this were true, the fauna would be referred to the Pliocene and the earliest stages of the Pleistocene and not to the later or true glacial Pleistocene. Question as to current reference is perhaps warranted by the extreme difficulty of closely correlating widely isolated formations in a transition period like the Pleistocene.

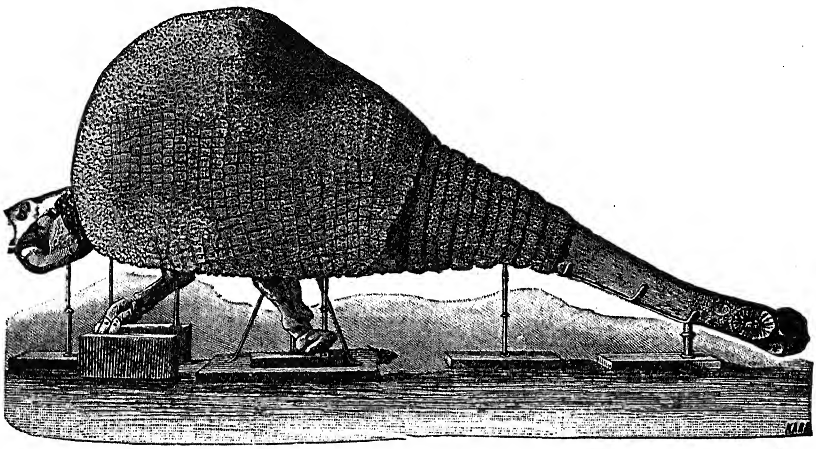


Fig. 566.—A club-tailed glyptodont, *Dœdicurus clavicaudatus,* from South America. (After Lydekker.)

Australian life.—Owing to the isolation of Australia from the Eurasian continent, its organic development followed lines of its own. The vertebrate fauna consisted exclusively of marsupials and monotremes. In general, they differed specifically from those now living, and were larger, on the whole. The subsequent dwarfing was possibly due to the less genial climate of the ice age, and is perhaps to be correlated in time as suggested above. Although the glaciers were but slightly developed on the Australian mountains, the region doubtless felt the effects of the wide-spread refrigeration of the higher latitudes, and of the aridity which seems to have accompanied some of its stages.

Life in Africa.—Comparatively little is known of the Pleistocene life of Africa. A moderate climate in the northern portion seems

to be attested by fluvial accumulations which have yielded remains of the buffalo, antelope, aoudad, hippopotamus, rhinoceros, and horse. These appear to have belonged to an early stage of the Pleistocene. A later stage is represented by mollusks of existing species, and a mammalian fauna embracing the elephant, buffalo, hippopotamus, urus, antelope, sheep, camel, and horse, a group differing widely in the main from the present occupants of the region.

Man in the Glacial Period.

In America.—Previous to the last decade of the last century, no small mass of prehistoric material of human origin had been assembled and somewhat widely accepted as conclusive of man's presence in America in glacial times. The rise of a more critical spirit in archæologic geology and the application of more rigorous criteria have, however, disclosed weaknesses both in the observational authentication and in the interpretation of the material, and all these data have been called into question, with the result that man's antiquity in America is a more open question to-day than it was thought to be fifteen years ago. While the doubts raised bore in some cases upon the human origin of the objects, they lay for the most part against the geological relations assigned them and the archæologic interpretations put upon them.

Prehistoric human relics in America range from the rudest stone chippings and flakings up through various gradations to skillfully fashioned and often polished handiwork in stone, metal, bone, and other material. The relics brought into question were chiefly, though not exclusively, those of the ruder sort. Following European precedent, the earlier students classed the rougher artefacs[1] as paleolithic, and interpreted them as indicating the presence of Paleolithic man and of the Paleolithic or Old Stone age in America. The better fashioned artefacs were classed as neolithic, with corresponding reference to the Neolithic or New Stone age. Some investigators very

[1] The term "artefac" has been coined to designate, in a non-committal way, any object that has been fashioned by man, in any way or for any purpose, or incidentally without purpose. It includes stone chips, broken and rejected material, and various forms of by-products, as well as implements, weapons, ornaments, etc. Its special function is to avoid the infelicity of using the words implement, weapon, etc., for objects that may never have been used, or even intended for use.

properly regard "paleolithic" and "neolithic" merely as stages of early art, and not as chronological "ages," or geologic divisions, but the terms have been much used in the latter sense.

The relics interpreted as paleoliths consist chiefly of rudely chipped pieces of flint, chert, quartz, or quartzite (Fig. 567). With these are associated other products of early art. The neoliths embrace a wider range of stone artefacs, which may be briefly typified for our purpose by the familiar well-chipped arrow-points, spear-heads, knives, and scrapers of flint or quartz, and by the ground and polished axes, chisels, pestles, mortars, and other implements of greenstone and similar

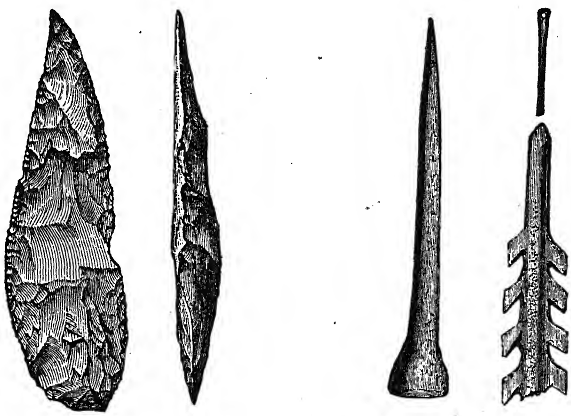


Fig. 567.—At the left, a typical paleolith from Kent's Cavern, Torquay, England, seen on the face and edge. At the right, a bone pin or bodkin, a broken needle, and a barbed harpoon head, also from Kent's Cavern. (After Evans.)

tough or workable rock. The ruder class were confidently interpreted as the work of an earlier and less cultured people, while the better class were known to have been the customary implements and weapons of the natives of the continent when first invaded by Europeans. Stone hammers have been found in abundance in the ancient copper mines of the Lake Superior region, and thus the use of stone and of copper implements is shown to have been contemporaneous; but this was long after the retreat of the last ice-sheet, and does not especially concern us here, except as it serves to emphasize the contemporaneity of different forms of art. It is helpful also to note that the phase of the stone art designated neolithic was dominant on the continent until very recent times, and is scarcely yet extinct, and that

it was thus contemporaneous with the " Iron age " of Europe and entirely overlapped the " Bronze age."

The chief points brought into question by the more critical inquiries of recent years were (1) the reference of the ruder artefacs to a stage of art more primitive than that of the Indians and other aborigines, and (2) the reference of the gravels and other superficial formations in which they were found to the glacial period.

By a series of notable investigations relative to the first, Holmes[1] reached the firm conviction that the early inhabitants of the country, like the later Indians, resorted habitually to gravel-beds and to outcrops of appropriate rock to procure the raw material for their stone artefacs, and that it was their custom to test and to rough-out the material on the ground, leaving the chippings and the rejected material scattered about. This preliminary work appears to have been done wholly by rough percussion with cobbles and other natural forms of stone picked up on the ground and used as hammers. The roughed-out flakes and other half-shaped forms that promised to work up properly, were usually taken to other sites for the finishing work. This half-worked material seems often to have been cached in quantity, and to have been material of trade. The more delicate and tedious work of final shaping was apparently done more leisurely, and as need required, at their dwelling sites or other convenient places, and to have been done by skillfully applied pressure rather than by percussion. An example of the refuse deposits on the face of the gravel bluff from which the material was taken is shown in Fig. 568. A selected series of rejects, showing progressive stages of reduction, is shown in Fig. 569. A full series of the stages of manufacture, as thus interpreted, is shown in Fig. 570.

By virtue of this separation of the process of manufacture into two parts, there arose a geographic separation of the products, a fact of importance in interpretation. The rude failures and rejects, together with the extemporized hammer-stones, cores, flakings, and chips, were scattered about the sites of the raw material, while the completed implements were liable to become fossilized, as a rule, only about the

[1] Holmes, W. H., A Stone Implement Workshop, Am. Arthropologist, Vol. III, 1890, pp. 1–26; Review of the Evidence Relative to Auriferous Gravel Man in California, Smith Rept. 1900, pp. 417–472; Stone Implements of the Potomac-Chesapeake Tidewater, Ann. Rept. Bureau of Eth., 1893–94, pp. 1–152, and Jour. of Geol., Vol. I.

dwelling sites, or wherever, in the course of their use, they were lost, broken, or thrown aside. In the light of this definite separation, it

FIG. 568.—Portion of an extensive deposit of shop-refuse, near the quarry face in a gravel bluff, on Piny branch, near Washington, D. C. (After Holmes.)

is not difficult to see how the similitude of two stages of art, of quite different aspects and geographically dissociated, arose, and how easily they might be misinterpreted.

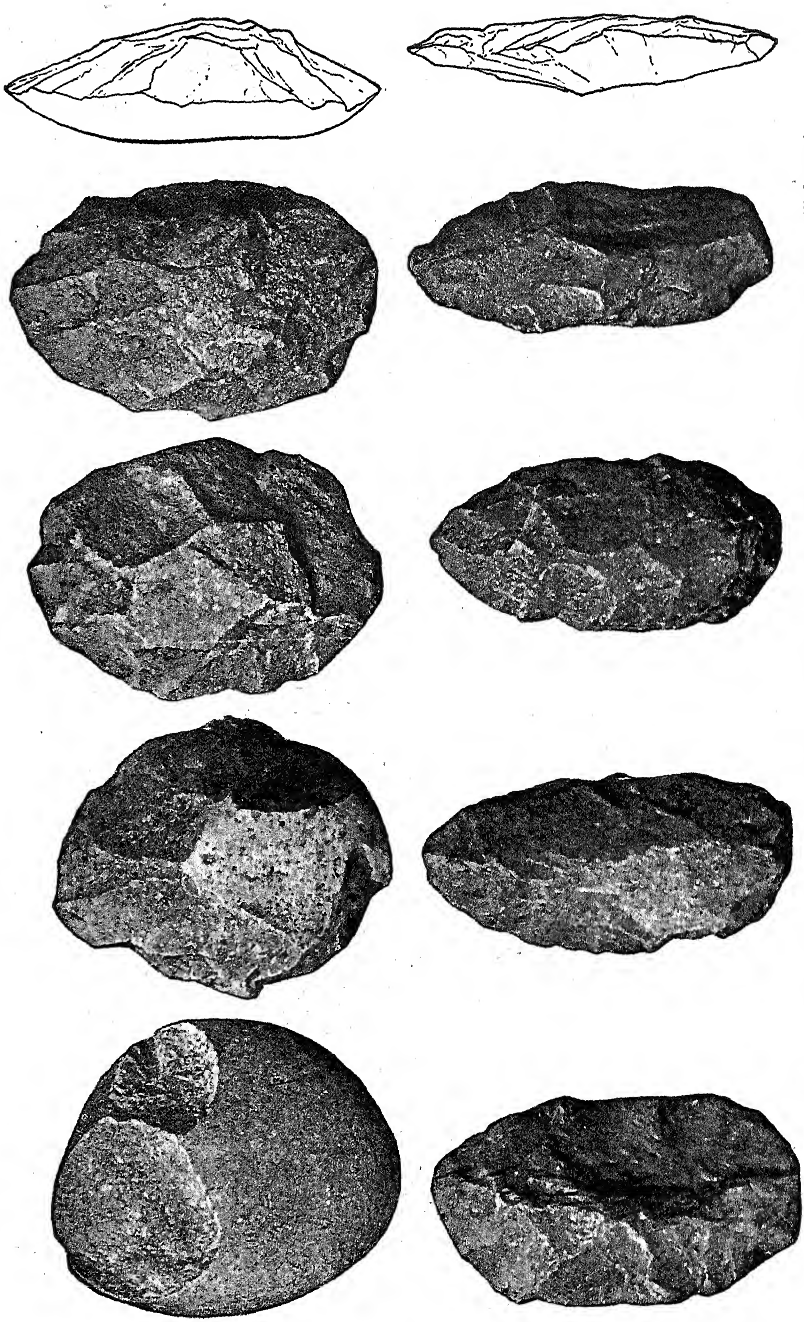


FIG. 569.—A progressive series of quarry-shop rejects, showing stages of reduction. (After Holmes.)

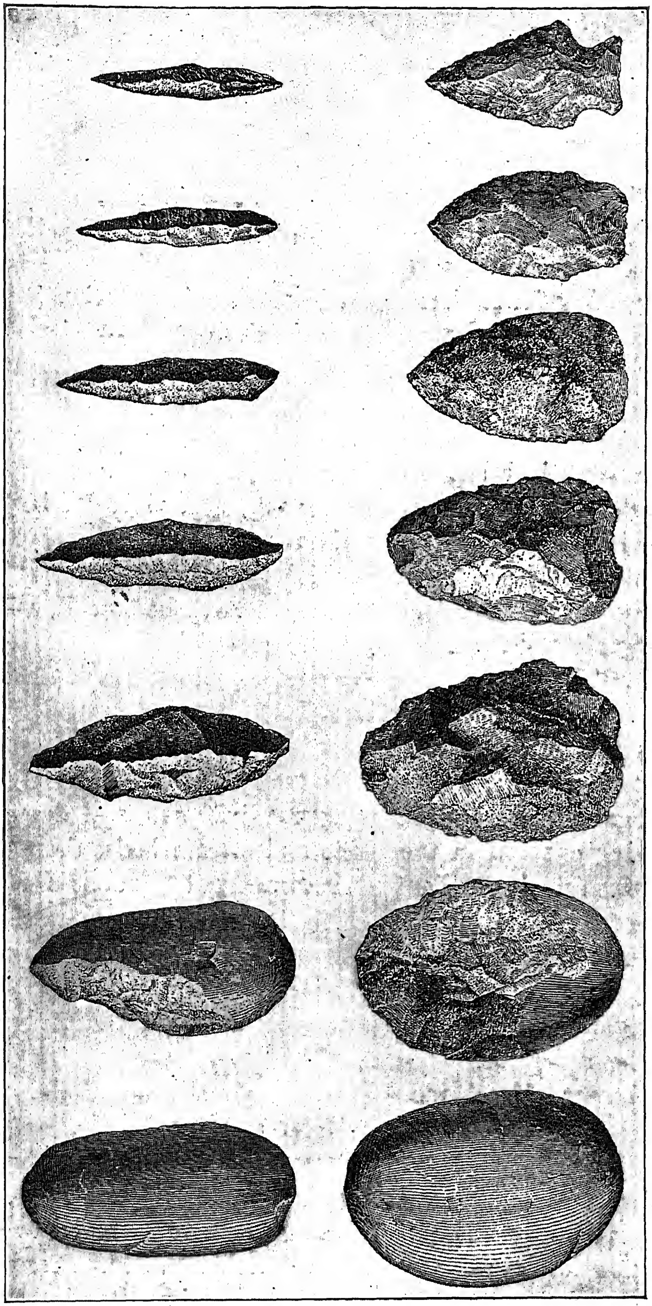


FIG. 570.—A series of forms illustrating progressive steps in the manufacture of arrow-points from quartz pebbles obtained mainly from shops and village-sites, near Anacostia, D. C. (After Holmes.)

The most available sites for finding suitable raw material in a convenient form were the river gravels and the terrace formations. This was especially true in and about the glaciated regions where valley trains of glacial gravels led away from the ice-fields. In these were usually much quartz, flint, chert, and other available rock, in the convenient form of pebbles, cobbles, and bowlderets. This material had been selected, as it were, and brought to workable sizes by the ordeal of glacial wear and wash.

It is a significant fact that the rude artefacs in question have been chiefly found in such gravels. Gravels derived from chert-bearing limestone or quartz-bearing rock are also fruitful sources. In other words, there is a correspondence between the distribution of the ruder artefacs, and that of the raw material. The distribution of the finished artefacs is much wider and more varied, and hence more consistent with the probable distribution of their use, and their liability to be lost. There is a special infelicity in supposing that great numbers of implements would be lost in glacial rivers during actual glacial stages, for the waters of these rivers must have been cold, silty, and barren of organic matter, as they came from the glacial mill under the ice-fields. They must have been among the most uninviting of all streams for hunting and fishing. But at later stages, when the climate was milder and the streams warmer and clearer, and when the adjacent country was filled with food and game, and when also the glacial gravels were undergoing readjustment and degradation, and were being exposed in the bluffs and stream beds, these streams must have furnished excellent and convenient grounds for finding raw material for making stone implements.

The distinct recognition of the two stages in the manufacture of the well known arrow-points, spear-heads, knives, etc., used by the known aborigines of the country, and the strong evidence that multitudes of the ruder forms found in the river gravels were products of the first stages of such manufacture, naturally raised the question whether there are any true paleolithic artefacs in North America. The difficulties of discriminating between "paleoliths" and "rejects," if indeed they can be discriminated, is illustrated by Fig. 571, one of the chipped blades of which has been regarded as a typical "paleolith," while the other forms are "rejects." Whether this close resemblance be regarded as merely similitude or as actual identity, it is obvious

that a special burden is thrown upon the geological evidences, and that they must be essentially decisive in themselves.

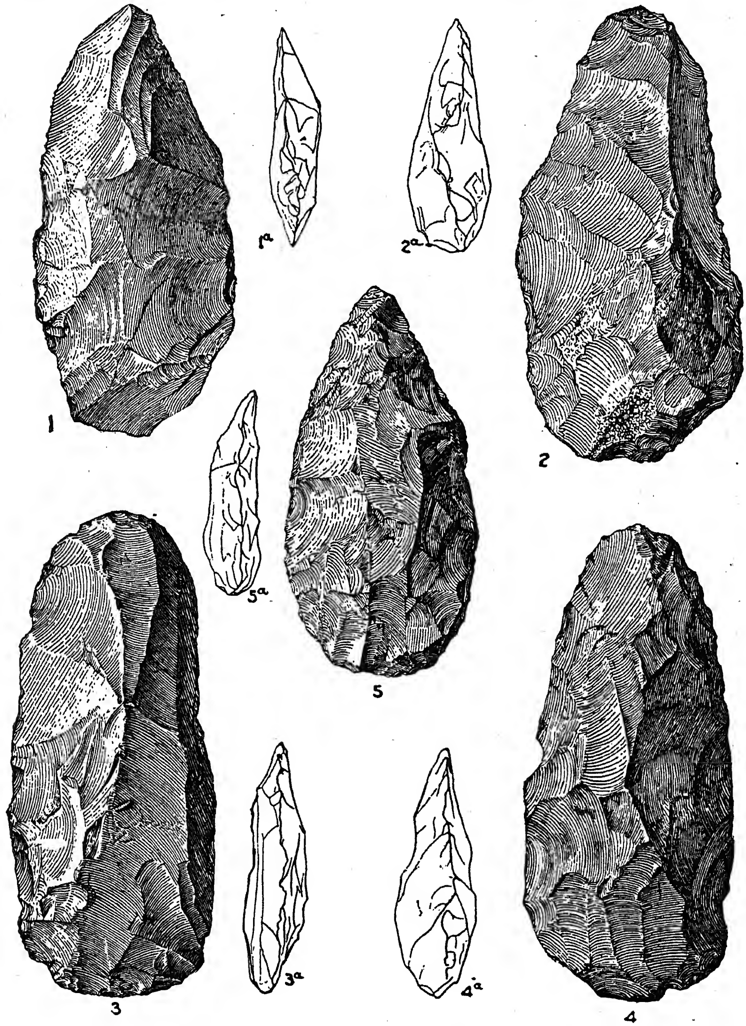


FIG. 571.—A group of figures of chipped-stone artefacs, one of which has been regarded as a typical paleolithic implement, front and side view, while the rest were obtained, in three cases, from modern flint-shops of the region in which the supposed paleolith was found, while the fourth was traceable directly to the same shops. The discrimination between the paleolith and the rejects is left to the reader. (Holmes.)

It has been found that by far the majority of the artefacs in the valley gravels are buried in the superficial portions, or in talus slopes,

or in secondary deposits, many of which are comparatively recent. Of the less superficial finds, many have been shown to be cases of secondary burial by natural means. The usual modes followed by streams

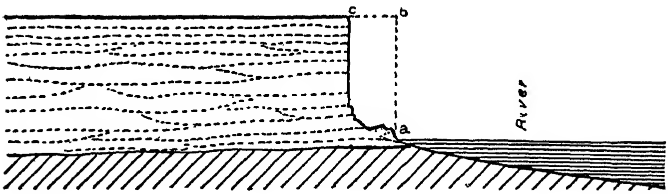


FIG. 572.—A gravel bluff formed by the under-cutting of the adjacent river. (After Holmes.)

in cutting down their channels in valley gravels are peculiarly well suited to bury superficial material to very considerable depths, for in their meanderings they cut into the bordering terraces or uplands

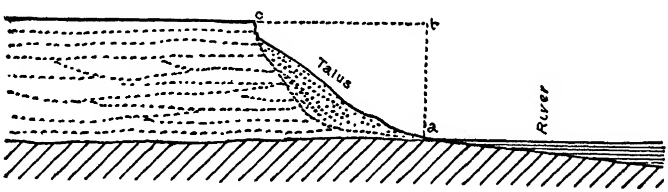


FIG. 573.—The same at an early stage of talus formation.

at intervals and develop steep bluffs. When the meanders shift, as they are sure to do, the bluffs inevitably grade down to a slope by the falling, or sliding, or washing of the top to the bottom, as illustrated in Figs. 572–574. What was in the top portion naturally becomes part of the base of the talus, and is deeply buried. Similar secondary burials take place in various kinds of loose material, includ-

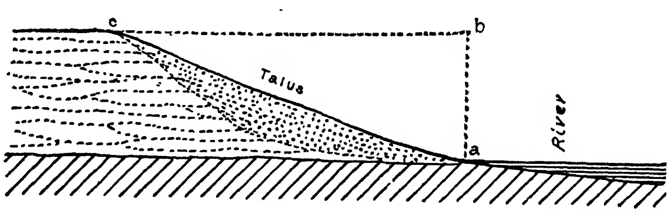


FIG. 574.—The same at a late stage of gradation, when the slope has become nearly stable.

ing loess and fluvial deposits of all sorts. It is to be noted that this is *a prevailing habit,* and not an exceptional mode of action.

While lateral action of this kind seems to have been the most common mode of burial of artefacs and other superficial material, other systematic methods are recognized.[1] One of the more important arises from the *scour-and-fill* of streams when they run on beds of gravel, sand, silt, or other loose material. The irregularities of a stream's flow, particularly the swirls and rolls developed by its meanders, give rise to shallows and deeps, and constantly shift them so that in time they cover nearly, or quite, the whole of the bottoms occupied by the stream. Similar action is to be assigned to all stages in the past history of the stream, and, hence, any article found in an abandoned terrace may as well be assigned to scour-and-fill just before the stream abandoned it, as to any earlier period. A valley train, heading at the ice-edge and hence usually called glacial without hesitation, is subject to this re-working process as long as the stream flows over it. The depth of re-working is readily measured by the depths of the deeper parts of the streams below their flood-plains, for it is known that these deeper parts are filled before the river bottoms become flood-plains or terraces. The depths thus re-worked very commonly range from one to three score feet for small rivers, and up to five or six score for large streams (Vol. I, p. 195), and in some cases, reach even three and four hundred feet. In view of this, *no relic found in fluvial material can, with full safety, be referred to an age older than the last stages at which the stream flowed over its surface.*

Almost none of the glacial gravel trains were at once abandoned by their streams, except in certain portions immediately adjacent to the ice-border; indeed most of the glacial gravel trains were built up in their lower stretches for some time after the glacial feeding stopped. This was done by the transfer of material from the high-gradient portions near the ice-edge, to portions of lower gradient below, as an inevitable consequence of the substitution of clearer waters for the overburdened glacial waters. There is then very little assurance that an implement, even if found deep in a glacial gravel train, was buried while the ice was present, unless it is found in the unshifted portions immediately at the ice-edge, and the topography and relations give

[1] Criteria requisite for the reference of relics to a glacial age, Jour. of Geol., Vol. XI, 1903, pp. 64–85. Some methods not mentioned in this work are there discussed.

full assurance that *the particular portion involved was not shifted.* Because of this fundamental difficulty, and of the great liability to misinterpret the secondary burials previously described, and because of some other contingencies we cannot here discuss,[1] it is scarcely possible to make out a good case of proof of contemporaneity with an ice stage, from relics found in river gravels, unless the inherent evidences connected with the relics themselves are altogether convincing.

All surface formations, however perfect their integrity in other particulars, are subject to surface disturbances, and to the intrusion of surface objects, through (1) the overturning of trees, (2) the penetration of roots, their subsequent decay, and the filling of the root-holes, (3) the burrows of animals, (4) earth-cracks developed by drouth, and various other incidental agencies. Wind-blown dust and sand also bury surface objects. All loose formations, glacial or otherwise, are subject to secondary modifications in these and other ways, to degrees and extents only appreciated by special students of such phenomena.

There is a rather important class of recomposed formations made by the shifting or rehandling (by eolian, pluvial, fluvial, slumping, and other processes) of drift, loess, or alluvium, which so closely simulates the original formations of like class as to deceive geologists of no little experience. Some of the supposed evidences of man's antiquity that seem, on their faces, to be strongest, are but cases of burial beneath such recomposed formations of comparatively recent date. Occasional burials of relics to depths of many feet may, therefore, carry little weight.

Sources of good evidence.—There are two classes of formations in which good evidences of glacial man, if there was such man in America, are to be sought, viz., (1) in undisturbed till-sheets below horizons affected by surface intrusion, and (2) in interglacial beds, where overlain by till and protected from all assignable sources of subsequent intermixture. Both these classes of beds have yielded fossils of other forms of life, and these alone have been seriously considered in the usual studies of the life of the glacial and interglacial stages. These beds have not yet yielded human relics in America, but they should do so in time, if man was a member of the faunas of glacial or interglacial times.

[1] Jour. of Geol., XI, 1903, pp. 74–75

In Europe, cave deposits have afforded a very important part of the evidence of man's antiquity, by showing that he was contemporaneous with a considerable number of animals that have become extinct, and by inherent evidences of age. In America the evidence of the caves is thus far essentially negative in this respect, the relics of man in caves being associated with the living fauna, with perhaps one or two doubtful exceptions. The mammoth and mastodon, as already noted, lived after the last known glacial stage, and very likely some other extinct animals did, so that an argument from association with extinct animals comes to have force only when the relics of man are associated with *a large number* of extinct animals which carry evidences, or at least the presumption, of having died out before the last glacial stage. In the American caves there is little or nothing in the depth or method of burial to imply great age.

When the weakness of the cave evidence is joined to that of the gravels and other loose deposits, and to the absence of authentic evidence from the glacial tills and the interglacial deposits whence the higher order of evidence is chiefly to be derived, presumption seems to lean to the negative side of the question, and an attitude of suspended judgment seems to be required. Proof of the negative proposition that man was not in America during the glacial period is not to be expected. His absence may in time come to be assumed, if good evidence of his presence shall not be forthcoming after due investigation under the more critical methods which the case requires and is sure to receive.

In Europe.—The question of man's presence in Europe during the glacial period is altogether independent of the American problem. The balance of evidence is wholly in favor of the eastern continent as the place of man's origin, and hence the dates of his migration to America, and of his appearance in Europe, respectively, are as independent as are the respective dates at which the Aryans entered the two regions. There is little doubt that the European data might well be subjected to more severe criteria, both archæologic and geologic, and that some at least of the data from the gravels and other loose formations would be found to have but little value. There are, however, some important differences between the European and the American data. The European are greatly superior in the mass of material gathered directly by geologists and archæologists, under condi-

tions of satisfactory scientific control. The European cave evidence seems to have no strict counterpart in America. In Europe there are numerous caves in which the relics of man, mingled with those of many extinct animals, have been securely protected by layers of stalagmite. While the ages of the stalagmite layers have rarely been fixed with certainty, or well correlated with the glacial stages, they bear inherent evidence of considerable antiquity.

The association of man with extinct animals is a phenomenon that may mean the extension of man's presence backward, or the extension of the animals' presence forward, and to this double-faced problem research has not yet furnished a final key. Obviously, however, the larger the number of animal types not known to have lived this side the last glacial stage whose remains are commingled with human relics, the stronger the presumption of man's presence before the close of the glacial period. From this point of view, the European case seems to be strong, while the American is weak.

There is one further feature in the European case that is, at least, suggestive. Two climatic classes of animals are associated with the human relics, according to various European writers,—a sub-arctic and a sub-tropical. Besides these, there are intermediate groups of temperate aspect, but these do not carry equal significance. On the sub-arctic side, there were reindeers, mammoths, woolly rhinoceroses, arctic gluttons, musk-oxen, and other boreal forms; on the sub-tropical side, there were lions, leopards, hippopotamuses, hyenas, southern rhinoceroses, and other African types. These contrasted groups, as interpreted by James Geikie and others, imply migrations of the kind already sketched as characteristic of the glacial period. While it cannot be positively affirmed that there were no climatic oscillations of a similar kind after the ice invasions ceased, there is a somewhat strong presumption that those implied by these two classes of animals were identical with some of the recognized climatic oscillations of the glacial period. This presumption connects man with at least the later of the glacial epochs.

The relics thus associated with extinct animals have been assigned to paleolithic man, and to a primitive stage of culture. They have been interpreted rather by the crudeness of the rude stone artefacs than by the evidences of a higher order of art which the record presents. If, however, the rude stone artefacs are susceptible of being

interpreted as the incidental products of preliminary processes in the production of a higher class of stone art,—an interpretation which does not seem to have been fully adjudicated, as yet, in Europe,—

FIG. 575.—Etching of reindeer on a slab of slate, from the bone cave of Les Eyzies, Dordogne, France (½ size). The next figure is from the opposite side of the same slab. (From a photograph, Prestwich's Geology.)

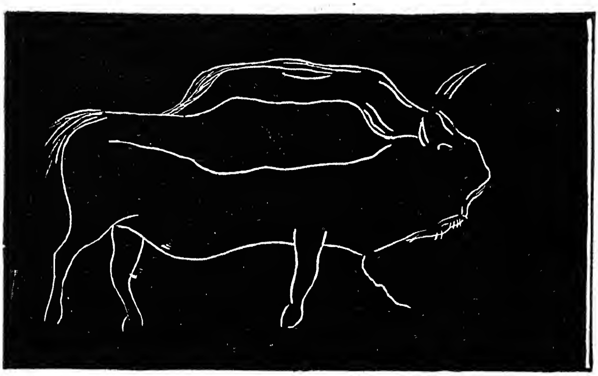


FIG. 576.—Sketch of an aurochs on the opposite side of the slab of slate showing the reindeer above. These sketches may be instructively compared with the similar work of the ancient Assyrians and Egyptians.

a more favorable judgment of the art of these ancient peoples would appear to be required by the other classes of relics found. There were associated with the stone artefacs, implements of bone, such as needles with perforated heads, awls or bodkins, harpoons or spears

with barbs, etc., implying some advance in art; there were carvings that show not a little skill, and drawings in which the elements of perspective and shading, as well as skill in delineation, are indicated (Figs. 575 and 576). These seem to imply a higher stage of art development than is obviously consistent with a limitation in the use of stone to the very crude forms called paleolithic. However this may be, present evidence seems to justify the conclusion of most European archæological geologists, that man was present in southern and central Europe during the later part of the glacial period.

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CHAPTER XX.

THE HUMAN OR PRESENT PERIOD.

The end of the Glacial period.—The termination of the Pleistocene or Glacial period is usually placed at the time when the ice-sheets disappeared from the lowlands in the middle latitudes of Europe and North America. Notwithstanding this conventional usage, it is to be noted that the ice-sheets had not then completely disappeared, and have not even now, for about 10% of the recently glaciated area of North America is still buried in ice. This lies chiefly in Greenland, the most central and northerly of the areas of glacial radiation in the permanent low-pressure area of the North Atlantic, and subordinately in Alaska, in the northeastern portion of the permanent North Pacific "low." These lingering residues of the last Glacial epoch signalize the fact that a complete emergence from the characteristic features of the Glacial period has not been reached.

If the speculative conception that the deep-sea circulation was actuated by evaporation in the low latitudes during most of the geological periods, and that this circulation was reversed by low polar temperatures in the glacial periods only, be true, the reversal in this circulation, when it shall take place, will constitute the really radical limit of the Glacial period; for when dense, warm, saline waters shall occupy the depths of the ocean, and emerge in the high latitudes, giving them mild climates, glacial conditions will have disappeared most effectually, and typical warm uniform climates, such as affected most geological periods, will have returned. This is, of course, hypothetical, and has its chief value perhaps in loosening the hold of our too-fixed presumption that the present atmospheric and oceanic conditions are normal for a late stage of the planet's history.

Future glaciation.—It is not absolutely clear that there may not be another recrudescence of glaciation before this series closes, but

the probabilities seem to be much against it. The declining series of oscillations already noted seems to have reached its last term. If carbon dioxide is an influential factor, its artificial production, which is rapidly increasing, appears likely to more than offset the consumption by natural processes, and hence to tend toward amelioration of climate; but the factors that coöperate to produce glaciation are too complex, in our view, to warrant more than a comfortable presumption of future immunity from ice-invasions until another great deformation shall have taken place in the distant future.

The end of the deformation period.—So, also, it is not wholly clear that the deformative period which started in the late Tertiary, and extended through the Pleistocene, is yet completed. We are accustomed to regard it as essentially passed, notwithstanding some movements still in progress; and, in the main, this seems to be justified by the probabilities of the case. It is uncertain whether the existing and very recent movements are to be regarded as portions of the main deformative movement, or as secondary adjustments following the main movement, or as but instances of the class of gentle movements that are ever in progress, even if we do not raise the question, as some geologists would, whether there is any real periodicity of movement at all.

The region of the lower St. Lawrence has been elevated relatively since the retirement of the ice, as is well attested by fossiliferous marine beds, and by shore-lines 600 feet above the present sea-level. This movement seems to have affected the North Atlantic coast from New England northward, but quite unequally at different points. It has been suggested by several writers that this relative rise might be chiefly a resilience from the depression due to the weighting and cooling which the region had suffered during the glacial stages.

A recent movement in the region of the Great Plains seems also to be suggested by certain physiographic features. Extensive tracts in central Kansas and Nebraska bear an aspect of pronounced topographic youth, suggesting that they have been lying, until recently, near the neutral horizon between erosion and deposition, and have lately been raised on the western side. In the Dakotas, there are broad gradation plains of abandoned river-courses which cross the present valley of the Missouri River. Their present gradients, and their elevation above the present river-bottoms of the region, also

imply a westward elevation. These and collateral phenomena, taken with the remarkable movement of the Keewatin ice-sheet from what is now the lower to what is now the higher side of the plains, seem best satisfied by the view that until about the close of the Glacial period the western side of the Great Plains was lower than now, or the eastern side higher than now, relative to the common surface-level. The composite view, that the area under the great ice-sheet was relatively depressed and the area on its western border relatively elevated, is perhaps the best special interpretation. On the western side of the continent there is much evidence of recent movement, some of which appears to have taken place since the close of the Glacial period, as usually defined. Similar phenomena affect other continents.

It is not therefore wholly clear whether the present is to be regarded as a part of that time of deformation which had its climax in the Pliocene, or whether it belongs rather to the initial stage of a period of quiescence that is yet to develop characteristically. It may perhaps best be regarded as a transition from the one to the other.

In any case, two movements are probably peculiar to it : (1) the elevation of the glaciated surface due to the removal of the weight of the ice-sheet and its return to a normal temperature, and (2) the restoration of the water temporarily locked up in the ice-sheets to the ocean, which tended to raise the sea-level, while the removal of the attraction of the ice-mass and the accompanying change in the position of the earth's center of gravity tended to cause the waters to recede from the glaciated region.[1] When the special effects of these exceptional agencies are deducted, the amount of the post-glacial movement is appreciably reduced, which is favorable to the view that the earth is now passing slowly into a period of quiescence.

The suggestions of existing physiography.—This view is further strengthened by the present physiographic features of the earth's surface. These are a direct inheritance from the Tertiary deformations superposed upon pre-existing configurations. They have been modified by the gradational agencies that have been working since, including the recent glaciation. They should tell us whether the face of

[1] The attraction of the ice-mass is discussed mathematically by R. S. Woodward, Bulletin U. S. G. S., No. 48, 1888; also, 6th Annual U. S. G. S., 1884–85, pp. 291–97. The effects of the accumulation and the melting of ice are discussed by Croll, Climate and Time, 1890, p. 388.

the earth is that of a planet in the midst of deformation, or that of one recently deformed, and now returning to a more quiescent state. On critical examination every stream should tell whether it has just been rejuvenated, or has done some notable work since it was rejuvenated, and whether the amount of rejuvenating influence is still being increased, or is static, or is being diminished. Every coast should show whether the continental border stands forth in the manner typical of an earth-segment just crowded up by a deformative thrust, or whether it has made some notable progress in settling back, or in being cut back, to an inter-deformative state.

The streams of the continents almost universally show that since they were rejuvenated they have had time to do some appreciable work, except in the case of small streams entering the deepened valleys recently occupied by glaciers, and the limited work of these only emphasizes the time implied by those streams that have done appreciably more work. Falls which owe their origin to the deformations of the recent deformative period abound on all the continents, but they are almost universally attended by canyons below, that show a period of activity of appreciable duration. These falls and canyons are often so related to slack water below as to show that the rejuvenating process was stopped some time ago; indeed it has often been reversed, as illustrated by the falls of the Potomac, and the rapids of the "Fall line" of the Atlantic border generally, and the depressed valleys below. The Falls of the Columbia, Congo, Zambesi, Brahmaputra, Yang-tse, and of a multitude of other rivers descending from the elevated portions of the continents, are also illustrations in point. If the various criteria of topographic age set forth in Volume I be applied to the face of the continents, it will be seen that, while they betray, very generally, evidences of rejuvenation by deformation in relatively recent times, there is very little to indicate rejuvenation in progress, except in features that are obviously local and special. While evidences of various degrees of aging are nearly everywhere displayed, the areas that bear the most declared evidences of topographic youth are those recently abandoned by the ice-sheets of the last glacial stage, and the ice-invasions seem to be the youngest of the rejuvenating agencies.[1]

If attention be turned to the borders of the continents, significant

[1] Jour. of Geol., Vol. XII, p. 707.

evidence is found in the fact that almost nowhere does the real edge of the continent appear above the ocean. Very generally it lies 100 fathoms below sea-level, and a continental shelf almost universally borders the continents. An area of 10,000,000 square miles, or more than 15% of the true continental surface, is thus submerged. This submergence took place so recently that the shelves are quite generally marked by trenches, valleys, and embayments referable to rivers that formerly crossed them, and which have not yet been concealed by sedimentation. These features imply that the continent was recently so deformed that these shelves were out of water, and that the rivers reached the true borders of the continental platforms. They equally imply a general movement toward continental submersion since, such, perhaps, as characterized many periods of past geologic history.

In passing, it is important to note that the almost universal presence of submerged continental borders has a very significant bearing on the fundamental question whether continental movements are simultaneous or reciprocal. If such movements were reciprocal, some continents should now be in the protuberant phase, with their borders as pronouncedly out of water as other borders are submerged. So, retrospectively, some should show marked participation in the elevation of the late Tertiary, while others should show as marked participation in the reciprocal submersion. In fact, however, all continents show signs of recent protrusive movement, and all show, by their trenched continental shelves, the early stages of a common movement of the sea upon the land.

The channels on the continental borders.—Wherever the continental shelves have been carefully explored by soundings, their surfaces show channels of river-like aspect, as already remarked. The fjords and submerged valleys of the northern coasts are the most familiar examples, as they have been much appealed to in support of the elevation hypothesis of glaciation.[1] The data in more southerly latitudes, especially on the Atlantic Coast from the Gulf of St. Lawrence to the Antilles, have been developed and emphasized by J. W. Spencer;[2]

[1] Among many others, Dana, Man. Geol., pp. 946–51; Upham, Bull. Geol. Soc. Am., Vol. X, 1898, pp. 5–10.

[2] Among other papers, Bull. Geol. Soc. Am., Vol. VI, 1895, pp. 103–140, and Vol. XIV, 1903, pp. 207–226; Am. Jour. Sci., Vol. XIX, 1905, pp. 1–15; and Am. Geol. XXIV, 1904, pp. 110–111.

those on the east side of the Atlantic by E. Hull,[1] by Nansen,[2] and others; and those of the Pacific by Geo. Davidson.[3] Many channels are so connected at the coast-lines with existing rivers as to leave no reasonable doubt that they are but submerged portions of the seaward extremities of the former channels of these rivers. Others, notably some on the California coast, are not so connected; but even these are usually interpreted as old drainage-valleys cut while the border of the continent was above sea-level. Besides these there are channels of more doubtful interpretation. Fjords, and the submerged shelf-valleys connected with them, are very numerous in the glaciated regions of both hemispheres, and undoubtedly owe some of their features, and perhaps some of their abundance, to glaciation; but Spencer,[4] Hull, Davidson, and others have shown that such submerged valleys are not confined to high latitudes or to glaciated regions. They appear to be phenomena common to essentially all coasts. Some of the best examples are the deep channels off the mouths of the Congo, the Indus, and the Ganges in low latitudes. Not only do channels cross the continental shelves, but troughs interpreted by Spencer and Hull as their continuations descend the abysmal slope on the outer edge of the continental platforms, to depths ranging from 7000 to 12,000 and even 14,000 feet; in other words, practically to the bed of the ocean. On the edge of the continental shelves, deep canyons have been identified, as the Hudsonian Channel, about 3800 feet deep.[5] These channels have usually been interpreted as evidence of vertical elevations of the continents whose borders they affect. The interpretation has usually been extended to the bodies of the continents, or at least to large portions of them. With the present evidence that essentially all continental borders are thus affected, and that the depths are in some cases nearly equal to those of the average ocean itself, a severe strain is put upon this interpretation, not only because of dynamical and faunal[6] objections, but because of the difficulty of disposing of the

[1] Trans. Victoria Inst., Vol. XXX, 1897, pp. 305–324; also idem, 1900 and 1902, and Geog. Jour., 1899.

[2] Rep. Arc. Expl., 1904, pp. 232.

[3] Proc. Cal. Acad. Sci., Vol. I, 1897, pp. 73–103.

[4] Loc. cit.

[5] Spencer, The Submarine Great Canyon of the Hudson River, Am. Jour. Sci., Vol. XIX, 1905, pp. 1–15.

[6] Dall, Tertiary Fauna of Florida; Wagner Free Inst. Ser., Vol. III, 1904, p. 1544.

water of the ocean when all the continents are lifted some thousands of feet, and because of a special difficulty of this kind involved in the fact that these valleys descend into *closed basins* such as the deeper parts of the Mediterranean and Caribbean seas and the Gulf of Mexico, which might naturally be supposed to retain so much of their waters as lies below the lowest notch in their rims however much they were carried up by epeirogenic movements. There are also difficulties connected with the forms and the gradients of the valleys.[1] The views of deformation outlined on previous pages (Vol. II, pp. 233–235) afford a different mode of interpretation, in which lateral movement plays a larger part, and vertical movement a lesser part, and in which the warping of *the border* of the continents replaces a movement of their general mass. This interpretation also embraces other border phenomena which need to be noted before the interpretation itself is offered.

Upward warping near the coasts.—Nearly every coast is bordered by inlets which are almost invariably submerged valleys; but, followed inland, these inlets usually graduate into deep sluggish rivers, and these, farther inland, are very often replaced by rapids or falls, or at least by steepened gradients. When the continental borders are examined throughout their full extent in all latitudes, the prevalence of this phenomenon becomes impressive. The chief exceptions are the great rivers which drain interior basins through broad gaps in the elevated tracts that so generally border the continents, as the Mississippi, which issues through the great gap between the Appalachians and the mountains of Arkansas and Indian Territory, and the Amazon, that issues between the Parima and the Brazilian mountains. A critical study of the gradients of the normal coast-border river-channels, embracing at once the submerged portions, the inlet portions, and the high-gradient portions, indicates a warping rather than a simple uplifting and depression, such as is implied in the epeirogenic conception. This is an important factor in the alternative interpretation.

The apparent imperfection of the geologic series on the continental borders.—It is most logical to infer that, as the continents were already outlined as early as Paleozoic times, persistent accumulation of sedi-

[1] Kümmel, Jour. Geol., Vol. III, 1895, p. 367.

ments should have been in progress about the borders of the continents ever since, and that there should have been built out from the borders a systematic series of Paleozoic, Mesozoic, and Cenozoic terranes, forming a distinct fringing zone. In this zone we might expect to find the most complete of all the stratified series, embracing representatives of all the ages and all the transitions, for on the borders of the continents sedimentation should rarely, if ever, have been wholly interrupted. This theoretical deduction is so strong that its verity can scarcely be doubted.

But an inspection of the geology of the coast-belts, as at present exposed, reveals the significant fact that not only is this theoretical deduction far from realized, but that the stratigraphic series is there singularly imperfect, indeed much inferior to that of the continental interiors.[1] The northeastern coast of North America and nearly the whole coast of Greenland are formed of Archean and Proterozoic formations, and the whole of the later series is essentially wanting. From Newfoundland to New York, the coast formations are mainly divided between the pre-Paleozoic and Paleozoic, with very scant representation of the Mesozoic and Cenozoic eras. From New York southward, Mesozoic and Cenozoic terranes have a fair, but not impressive development, while the Paleozoic are scarcely identifiable outside of the crystalline belt. On the west coast there is an intricate series, much interrupted by crystallines of more or less doubtful ages, which, if it could be fully interpreted, might more nearly fulfill theoretical expectations; but this is uncertain. In South America, long stretches on the northeast and southeast borders consist of crystalline rocks of ancient aspect, save for narrow tracts of younger beds on the immediate coast. There is no suggestion of a great systematic series. The eastern coast-tract of Patagonia more nearly meets expectations relative to the later periods, in that it constitutes a wide sloping plain of sediments heading at the Cordilleran axis on the west, and dipping beneath the Atlantic on the east; but this seems to be rather an extension of the interior plain of the La Plata basin than a typical fringing series. On the west side of South America, crystalline rocks, some of older, some of younger age, form complex terranes along or near the coast throughout more than half the length of the continent, while

[1] The geological maps in Berghaus' Physical Atlas afford the means for such an inspection.

the sedimentary series for the remaining distance seems to be complicated and imperfect. On the borders of Europe, from the White Sea to the Skager Rack, little beside Archean and Proterozoic terranes appear, while the later terranes are mainly unrepresented. In Scotland, Wales, Ireland, Normandy, and the Spanish peninsula, ancient crystalline rocks, interspersed with Paleozoics, largely occupy the coast or closely approach it. A crystalline belt is represented as lying a little back from the coast throughout nearly the whole extent of the western side of Africa, and this is scarcely less true of the eastern side. Although newer formations lie between this and the coast, they represent, according to present knowledge, but a small part of the post-Proterozoic series. The southern and eastern coasts of Asia are occupied by a much-interrupted succession of various formations in which none are conspicuously dominant, and no systematic series is indicated. The protruding peninsulas of India, Anam, and Korea seem to be largely formed of very ancient terranes, except some little fringings of quite recent deposits. In Australia, crystalline and Paleozoic rocks are predominant at or near the eastern coast and along much of the western, and there is little or no suggestion of an encircling belt of sediments systematically representing outward growth of the land.

And yet in the interior of all these continents there are great series of sediments recording much more fully the progress of the ages. If our knowledge of the progress of events were limited to coast-border series, it would be imperfect indeed.

None the less, we must believe that the theoretical continent-bordering series exists, and for ourselves we do not question that it is absolutely continuous, in its deeper parts, from the Archean to the present time. There must therefore be agencies in play other than the mere systematic lodgment of sediments about the continental borders, and these agencies have persistently disturbed the border record. If the mutilated record of the border-sedimentation be associated with the deep trenches of the surface and abysmal slope of the continental shelves, and with the rejuvenated streams and "fall lines" of the tracts lying back from the coasts, a possible solution of the common problem may be found in the habitual mode of behavior of the continental borders.

The Behavior of the Continental Borders.

We conceive the continental borders to have been affected in their own special and peculiar way by (1) body-deformations of the globe, (2) movements of the outer shell, and (3) movements of the sediments. With these were combined coöperative actions on the part of the sea and of the land-drainage.

(1) **The effects of body-deformation.**—If the body-deformations consisted, as we have supposed, of a downward movement of the ocean-basins and a *relative* upward movement of the land, it was obviously at the borders of the continent that the transition from the one to the other took place, and hence they were the tracts in which warping was specially felt. The basin sectors are thought not only to have sunk relatively more, but to have crowded somewhat upon the land sectors, and hence at their junction the sea-bottom tended to sink, and at the same time to push under the land, while the latter tended to rise relatively, and perhaps even to spread above toward the ocean basin. In normal cases, this tended (1) to depress the outer border of the continental shelf, which may be supposed to have been built out upon the border of the sea-basin by progressive sedimentation, and (2) to submerge the stream-channels there, while (3) the region back from the coast was warped upwards, the streams being thereby rejuvenated and the conditions provided for the formation of the rapids of the infra-coastal tracts.

(2) **The movement of the outer shell.**—If the view that an outer shell three or four miles thick shears over the inner body of the earth be correct, it will be readily seen that if the shell is thrust landward over the newly deformed surface of the inner body, the continental shelf would probably be pushed up the landward slope and so caused to emerge obliquely from the sea, the extent of the emergence being dependent on the extent of the lateral thrust, and the degree of inclination of the shear-plane beneath. The shell must move enough, taking the globe as a whole, to give rise to the mountain folds and the overthrust faults of the several periods of deformation, and this was considerable, even on the most conservative estimate. Just how this motion was distributed over the globe is uncertain; but the more the evidence is studied, the more the conviction grows that the movement was very general, and not necessarily confined to particular basins and con-

tinents. A very wide-spread movement that concentrated the folding along a few lines seems best to accord with the observed results, and to involve the least shrinkage, although it involves the most shear. But however distributed, if all the crustal wrinkling that took place in the late Tertiary is to be accounted for by lateral movement of the outer shell, its amount cannot have been inconsiderable, and the thrust of the shell up the bordering incline of the sub-shell body of the continents, must have been competent to carry a zone of the submerged portions of the shell obliquely out of the water, and permit erosion to channel its surface.

The reverse movement of the shell.—The squeezing-up of the continents by the lateral crowding of the heavier sub-oceanic sectors increased the difference in height between the continental surfaces and the bottoms of the ocean basins, and hence increased the tendency of the continental mass to creep laterally. So, also, the pushing of the shell up upon the more elevated continents, and the bowing of it up in wrinkles on their borders, furnished the conditions for a slow reverse movement. It is therefore reasoned that, following the great deformative movements, there would have been a much slower, glacier-like creep, both of the under-body of the continental platform and of the superficial shell, whose movement was facilitated by the supposed shearing zone between them. The movement of the shell is presumed to have been much the greater, because its previous movement and its distortion had been much more considerable, and because whatever movement took place in the mass below would carry the shell with it, while the independent motion of the shell would be added to this. The reversed movement of the shell, at the borders of the continent, would carry the surface next the coasts, now affected by valleys, down the slope, and submerge it. The body of the earth, meanwhile, had undergone little change besides shrinkage.

(3) **The movement of sediments on the continental edges.**—The sediments of the late periods are generally soft. There is good reason to suppose that the muds and sands which chiefly formed the sediments built out at the edge of the continental shelves usually remained incoherent for long periods, except where there were special cementing agencies. Now the attitude of these *was changed by the deformative movement* both of the earth-body and of the shell, and in so far as they were pushed above the sea-level, their weight was increased some 70%.

These changes of slope and of gravity obviously tended to cause these soft beds to creep back toward the abysmal basin. This tendency may well have been greatest at the edge of the continental shelf, where the newer and softer beds may naturally have been thickest. This creep may therefore have carried the outer ends of the channels previously formed, down to depths much below the relative horizons at which they were eroded. Adjacent to the deep channels off the mouths of the Congo, the Indus, and the Ganges, the edge of the lower part of the continental shelves is observed to be somewhat protrusive. This may, of course, be due to greater building-out at these points; but the fact is at least consistent with the conception here entertained and the contours are observed to be spread apart on the base of the slope, instead of being crowded together as might be expected from normal delta-building.

Coöperative water-displacement.—The basal deformative movement, by deepening and extending the great basins, tended to draw down the waters on the borders of the continents and hence aided in the emergence. The postulated reversed movement of the shell and the continental platforms tended in the opposite direction and aided in the subsequent advance of the sea on the continental border. So, too, the accelerated stream-erosion resulting from the increased protrusion of the land tended slowly to lift the sea-level by the transfer of sediment from land to sea.

Tidal coöperation.—Under any hypothesis it seems remarkable that river-channels could be submerged without being filled in the process, for the rivers must have been carrying detritus, and coastwise currents must have swept drift into the channels. River waters can scarcely be supposed to have been very efficient in erosion after they reached the coast, for they were fresh and relatively light, and should have spread out on the surface of the salt waters. The efficient agent in the case was probably the tides. Their entrance and exit, particularly where the river-mouth broadened to an estuary, as it was likely to do at the beginning of a submergence after a period of active erosion, doubtless scoured the channel, and not improbably enlarged and deepened it where the coast configuration was favorable. This was not improbably true of some of the channels at all subsequent stages of submergence, where they were favorably situated relative to tidal movements, and such channels may owe not a little of their

breadth and depth to this abetting action of the tides. Particularly may this be true of channels at the outer edge of the continental shelf, where the abysmal slope joins the more nearly horizontal surface of the shelf. We do not find that the subject has been made one of direct investigation, but the following data bear upon it. The speed of the main Atlantic tide is estimated at 520 miles per hour. Computation indicates that on the outer border of the continental shelf the speed is normally about 100 miles an hour. In other words, in passing from the deep ocean across the sloping shelf to the shallow water above the shelf, the velocity is reduced 75%, and a portion of the energy is necessarily converted into a wave of translation with erosive power.

It seems therefore not improbable that the trenches in the outer edge of the continental shelf, and on the abysmal slope, are scoured to greater depths and widths, and extended beyond their original limits, by the tides. Such action might apparently be assigned to any part of the abysmal slope on which the retardation of the tidal wave was sufficient to give rise to a wave of translation. This is consistent with the fact that the valleys on the abysmal slopes are broad, and have gradients much higher than those appropriate to river-valleys of like breadth.

If the foregoing conceptions of the behavior of the continental borders are valid, it is not difficult to understand why the theoretical fringe of sediments is so poorly represented above the sea-level, for it has been borne down and thrust landward by each general deformation, and has crept outward and downward with each relaxation. The whole series is to be regarded as present in the continental shelf and the coast-border tract, but as largely concealed by this combination of disturbing processes. When the great depth of the ocean-basins at the edge of the continental shelf is considered, it is obvious that the volume of sediment required to build the shelf seaward is large in proportion to the extension of the shelf, and hence the fringing zone is not very broad.

If the very general prevalence of harbors and inlets on the continental coasts is due to the foregoing combination of agencies, its importance to commerce is difficult of over-estimation.

Coöperative agency of the ice-sheets.—In the glaciated regions, especially such as had much relief, like Scandinavia, Greenland, and British Columbia, the ice itself, by its pressure and its own lateral move-

ment, must have aided the shear of the crustal shell beneath it. This may be among the reasons why fjords are so prevalent in these regions.

THE LIFE OF THE HUMAN PERIOD.

In the seas, and on the land in the tropics, the life of the Pleistocene appears to have passed by imperceptible gradations into that of the present period. In the higher latitudes, the transition was marked by two exceptional features, the re-peopling of the lands laid waste by the ice-incursions, and the invasion of the human race. We say invasion of the human race advisedly, for whatever may be true in the low latitudes, where the race perhaps came into its peculiar function gradually, in the higher latitudes the apparition of man took on the aspect of an invasion; indeed, from the point of view of other living creatures, it came as an irresistible inundation. Thus far man's dominance has been most pronouncedly a mid-latitude movement, with less pronounced potency in the very high and the very low latitudes, but even these latitudes are not likely long to escape the overwhelming supremacy of the new dynasty.

The re-peopling of the glaciated areas.—The re-peopling of the northeastern half of North America by plants and animals after the retreat of the last ice-sheet was not only the greatest event of this class, but may be studied to greater advantage than the similar event in northwestern Europe, because of the uninterrupted thoroughfare between low and high latitudes. Laporta has called attention to the barrier interposed by the Mediterranean to the free re-peopling of Europe after the ice-invasions. He notes that certain plants that abounded in Europe before the ice-invasions, were forced across the Mediterranean, or southeastward into Asia, and did not recross the barriers of water and desert on the resumption of a congenial climate in Europe. No such barrier intervened in North America. There was, however, an ill-defined climatic barrier between the arid plain region of the southwest and the humid forest region of the southeast. There is abundant evidence that open plains and arid climates had developed in the western region in middle latitudes in the late Tertiary periods, and that these were retained, with modifications and perhaps brief interruptions, throughout the glacial period and have become a present inheritance. Among these evidences are the repeated drying-up of

Lakes Bonneville and Lahontan, the distinctively arid topographies of the west—the mesas, buttes, and canyons that only an arid environment can develop—the evolution of the xerophytic floras that have been transmitted to the present stage, and the special faunas adapted to and dependent on these xerophytic floras. The aridity that gave rise to these physiographic and biologic evolutions probably had its center in the zone of descending atmospheric currents which should normally have lain near the thirtieth degree of latitude, but which, in this hemisphere, is now, and probably was then, shifted to the northward by the configuration of the great bodies of land and water. The pre-glacial arid tracts seem to have had a distribution in the western part of our continent not unlike that of to-day, while the eastern half of the continent was then, as now, more moist, and covered with forests rather than herbaceous vegetation. With the invasion of the ice of the glacial period, the floras and faunas were forced southward, as described in the story of that period, but differentially in the two sections. In the west, the northern life was driven by ice behind, hemmed in by mountain and other barriers at the sides, and resisted by arid tracts in front. The arid tracts were themselves forced to retire in some measure, but the lateral restraint of biotic migration became increasingly formidable as glaciers gathered on the mountain heights and occupied the passes. As the trends of the mountains were mainly north and south, they demarked a series of meridional tracts which directed the life migrations. There was therefore but little of the east-and-west intermigration that might otherwise have prevailed. Even on the plains east of the mountains, the climatic differences seem to have appreciably restrained east and west migration.

In the eastern half of the continent, the forests and forest-life were driven southward in the more unrestrained way already described, but for the greater part they kept within the eastern humid tract.

Following the last ice-retreat, the life of each of these sections moved northward, each biotic zone, arctic, subarctic, cold-temperate, and temperate, expanding as it went. It was as though the life-zones were elastic bodies which had been compressed to narrow limits about the edge of the advancing ice, and then recovered their normal breadth as the ice-pressure was withdrawn. The arctic or tundra flora and fauna that had probably been crowded into an almost vanishing zone fringing the ice-sheet, moved northward through about 20° of latitude,

and expanded to a breadth of 600 or 700 miles in the northern part of the continent. It spread even beyond, occupying the arctic islands and Greenland, where not covered by perpetual ice or snow. The zone of this arctic flora and fauna now lies mostly north of 60°. The sub-arctic zone of stunted conifers moved about 12° northward, and expanded into a zone some 400 to 600 miles wide. The cold-temperate belt of deciduous and evergreen trees moved a less distance, but expanded almost equally, while the warm-temperate flora spread itself over the territory abandoned by the last. With each of these vegetal zones went the appropriate fauna. The musk-ox, whose remains have been found skirting the glaciated area in Pennsylvania, West Virginia, Ohio, Kentucky, Indian Territory, Missouri, and Iowa,[1] has since retired to the extreme arctic regions. The reindeer, which had a similar distribution about the ice-edge, made a similar but less extreme migration and still occupies the barrens of the northern border of the continent; while the fur-clothed animals distributed themselves through the three northerly zones, most notably the sub-arctic zone of the conifers.[2]

The westward spread of these floras and faunas of the southeastern regions seems to have been meager, and individual rather than general. On the whole, the southwestern arid and prairie floras and faunas seem to have had the better of the contest with the forest forms, and to have spread eastward in the mid-latitudes at the expense of the southeastern group; at least arboreous vegetation is found appreciably farther west in interglacial deposits than on the present surface. This does not seem to be equally true in the higher latitudes, where the trees of the eastern group are distributed far to the northwest. Intermigration between the floras of the east, the west, and northeastern Asia, seems to have been less restrained in this northern region, doubtless because the climate was there less differentiated into moist and arid portions.[3]

The arid and semi-arid floras and faunas of the southwest seem

[1] Hay's Catalogue of Fossil Vertebrates in North America, Bull. 179, U. S. Geol. Surv., 1902.

[2] Some of these and other features are suggestively discussed by C. C. Adams, The Post-Glacial Dispersal of the North American Biota, Biol. Bull., Vol. IX, 1905, pp. 53-71.

[3] Adams, loc. cit.

to have been quite successful in pushing the more boreal and arboreous forms to the northward, or in forcing them to ascend the mountains; but the movement was less sweeping and more complicated than that of the east, because of topographic interference and the restraints of the lingering mountain glaciation.

In this re-dispersion of the North American faunas and floras there is a world of suggestive detail of which only a small part has been worked out into clear definition. From the viewpoint of investigation, it is a rich and almost virgin soil, forming the turn-row, as it were, between the more cultivated fields of the geologic and biologic sciences.

The rate of re-distribution.—Most of the plants were so well provided with means of dispersion by winds, birds, or other agencies, that they doubtless followed the retreat of the ice nearly as fast as climatic conditions permitted, and the abandoned ground was thus promptly clothed with such vegetation. But certain forms were not provided with these devices, and their relatively slow rates of migration furnish an independent mode of estimating the time since the ice began to retreat. That which we have really to estimate is not the least time in which given plants could migrate the required distances, but the time normally occupied in the migration of an associated group of plants, or a plant-society, some of which were slow migrants; for the plants are now grouped according to what seem to be their natural relations. They are not sporadically mixed as if they were in process of individual migration independently, each at its own pace. This group-migration is, however, difficult to deal with, and cannot here be discussed. To illustrate studies on individual migration, the walnut family is one of the most suitable, for walnuts and butternuts are so unwieldy as to be habitually carried but limited distances and buried by nut-eating animals, while the bitter hickory-nuts (pig-nuts) can scarcely be presumed to have been purposely transported and planted by the aborigines. There is little reason in any case to think that transplantation was practiced by the pre-Caucasian peoples of the eastern wooded regions, or that accidental transportation by them was an appreciable factor in the dispersal of the plants, for if it had been, the plant-grouping should betray it. But the distribution of the edible hickory-nuts is not, so far as we can learn, more extensive than that of the inedible species, and

each has its own appropriate grouping in plant society, and neither has a grouping that seems to have any relation to the homes of the aborigines.

Aside from the spreading due to the outward growth of the limbs of the parent-tree and the slight aid of winds, the distribution of these trees seems to be chiefly dependent on squirrels, which have the habit of carrying the nuts short distances and burying them for future use. Now if 15 years be taken as the average time at which a seedling under native conditions comes into bearing, and if a squirrel is always present to carry the first-borne nuts an average distance of 75 feet for burial, and always in the right direction, and always neglects to recover them, and they always grow and escape destruction, the average rate of migration would be five feet per year, or a mile in 1000 years. At least four species of the family are found 300 miles back from the former ice-limit, and the migration must have been greater than this to the amount that these trees were driven beyond the ice-border by the severity of the glacial climate. An appreciable portion of the distance was against a rising slope where the drainage was antagonistic, and it needs to be observed that streams, swamps, wet meadows, and other features were barriers to assistance by squirrels. Where the drainage favored, the dispersal might obviously be much accelerated. But if only the adverse slopes be considered, the time-estimate is larger than those derived from the erosion of falls and other physical methods. In the present state of knowledge, it is for each to judge for himself whether the uncertainties of the biological method of estimate are greater or less than are those of the physical, and what is the purport of their combined testimony.

The Dynasty of Man.

Human dispersal.—As yet there is little geological evidence relative to the place of man's origin, or to the earliest stages of his development. Various considerations connected with his physical nature and his distribution seem to point to the warm zone of the eastern hemisphere, preferably southern Asia, as the place of his appearance. There are some grounds for the inference that the earliest developments of those qualities that especially gave him dominance were associated with the open tracts of the sub-tropical zone, where rela-

tively dry descending air-currents prevailed, rather than with the dense forests of the equatorial belt where ascending air-currents and excessive humidity prevailed. Subsequent history, as well as the nature of the case, teach us that extreme desert conditions and excessive heights are prohibitive, that semi-arid conditions of varying and precarious intensities lead to nomadic habits, sparse distribution, and limited social and civic evolution; while well-watered plains and fertile valleys, under congenial skies, invite fixed habitation and the development of stable civil and social institutions. Excessive humidity and dense forests, on the other hand, tend to limitation and repression, in a primitive people, as does also extreme ruggedness of surface. Ascending atmospheric currents, with low barometer, high temperature, air-saturation, excessive precipitation, and lowering skies tend to physical and intellectual lassitude and inactivity. Descending atmospheric currents, high barometer, dry air, cool temperature, and clear skies tend to physical and intellectual activity. In a primitive state, before the control of accessory agencies was adequately acquired, it is presumed that a warm climate was more helpful than a severe one. From these considerations and from historical evidence arises the presumption that the primitive centers of virile evolution and radiation of the race lay somewhere in the open or diversified country of the warm tract of the largest of the continents, between the excesses of aridity and humidity, expressed in the deserts on the one side, and the dense forests on the other. From this, or from some analogous tract in that quarter of the globe, there seem to have been four great divergent movements. These were complicated by reverse movements, cross-migrations, and various anomalies, but only the dominant features can be mentioned here, and these but briefly.

(1) The most voluminous movement seems to have been northeastward between the great desert and mountain tract of Central Asia on the one hand, and the Pacific on the other, attended by divergences eastward to many of the islands of the Pacific. When the higher latitudes were reached, there followed a lateral spreading both east and west, encircling the arctic regions, and sending a branch down the full length of the American continent. This movement embraced the great complex of Mongoloid races, including the Malayan and the original American races. Previous to the disturbing events of recent centuries, this branch had developed three notable centers of civiliza-

tion, the Chinese in Asia, between the tropics and the parallel of 40° N. Lat., and between the desert on the west and the sea on the east; the Mexican in North America, between similar latitudes and in a similar atmospheric environment; and the Peruvian of South America, in equivalent physiographic surroundings. From these more advanced centers of evolution there was a gradation in all directions, and through various stages of partial civilization, to nomadic tribes, scattered hunting-bands and isolated families of limited attainments.

(2) A second and much inferior movement to the southeast, reaching into the southern hemisphere, gave rise to the Australioid and associated races which have thus far failed to rise to the higher civilizations, or to develop notable power.

(3) To a third movement to the southwest is assigned the peopling of Africa south of the Sahara with the negroid and associated races, which have had a voluminous but not powerful development.

(4) The fourth movement was northwestward across or around barriers of desert and mountain, to Western Asia, Europe, and North Africa, and gave rise to the most virile and progressive branches of the human family, the Xanthochroic (fair-white) and the Melanochroic (dark-white) races of Huxley's classification. The more or less decayed trunks of these branches still remain in Western Asia. Three chief passageways across the barriers seem to have been utilized in this movement, and in these passageways the most notable of the early civilizations developed, in transit as it were, and lingered for long periods. These passageways were (1) the Red-Sea-Nile-valley avenue, in which the dark-white and the Ethiopian races mingled, (2) the Euphrates valley, the central avenue of the Semitic races, and (3) the intermontane tracts of the Iranian plateau, the probable pathway of the ancestral Aryan races, and quite certainly the pathway of the later backward migration of the Aryans that gave the Brahminical elements to India's early civilization.

Ignoring the feeble Australian movement, the three great divergencies in the Old World were suggestively related to the physiographic features of the region, particularly to the great desert tract that stretches from the Sahara to the Gobi, having the Ethiopians on the south, the Mongoloids on the southeast and east, and the Caucasians on the north and west. While inferences from physiographic relations may easily be pushed too far, there is little doubt that they were very influential

in the early evolution and distribution of the human race. Relationship to the open, semi-arid, or mildly humid plains and fertile valleys that bordered on the desert barriers, was probably influential in leading to that control of the plant and animal kingdom that has made man the most influential of all biological agencies. Powell and others hold that agriculture owed its chief early evolution to arid conditions which induced man to irrigate and cultivate the plants necessary for his sustenance, and tended to fix his abode in the watered tracts. It is urged that the watering and slight culture of chosen plants in an arid tract was a less formidable task to ill-equipped primitive peoples, than the subjugation of competitive plants in a humid region. However this may be, there are various reasons why the open lands of semi-arid or mildly humid regions, with their varied floras and faunas and their active expansive life, with its sharp competitions in fleetness, alertness, and sagacity, and its occasional crises of drought and storm, should have fostered a favorable evolution in primitive man. The cereals he learned to cultivate were chiefly members of the grass family that grew natively on the plains, and the animals he domesticated were largely also those of the plains. To us it seems also significant that the centers of early civilization were all regions of relatively high barometer, of descending air-currents, and of semi-arid or mildly humid atmospheric conditions, all of which seem to be more favorable to activity of mind and body than prevailing low barometer, ascending air-currents, and humidity.

The physiographic associations of the progressive stages of civilization of the white races are suggestive. The most ancient recorded civilizations lay in the valleys of the Nile and Euphrates on fertile plains, but bounded by inhospitable deserts or mountain tracts, and in latitudes near 30° N. The somewhat later civilizations of Assyria, Palestine, and Phœnicia lay a few degrees farther north under similar conditions, but with sea-contact, another of the expansive influences, added in the case of Phœnicia. The succeeding civilization of Greece lay about 5° farther north, under clear skies, pure dry air, high barometer, and abundant sea-contact. The center of the more virile and militant Roman civilization lay still another 5° farther north. The later medieval and early modern civilization centered about France, another subequal step northward, while present gravitation of power and intellectual development is toward still more northerly latitudes.

"*Northward* the star of empire takes its way" is quite as true as the more familiar apothegm, and carries a more obvious causal suggestion, that of the need of a progressively higher degree of stimulus from low temperature, as man increased the means of his control of natural agencies. The modern movement has also been somewhat more toward mildly humid and forested regions, perhaps because man's superior resources have led to the removal of their deterrent features, and have permitted a larger utilization of their advantageous ones. It is also a question whether, at the present stage of the development of man's nervous organization, a somewhat less stimulative atmosphere may not best conserve his energies, and give steadiness, persistence and endurance to his sufficiently aggressive endeavors. The comparative results that shall arise from the different physiographic conditions in North America, where the same race under the same institutions is subjected to wide ranges of barometric states, temperatures, air-movements, humidity, and topography, may well be watched with interest. The exceptionally rapid evolution of the American people, an offshoot of the older peoples of the Eurasian Occident, and the similarly rapid evolution of the Japanese people, in some sense an offshoot of the more ancient peoples of the Eurasian Orient, are to be studied on their own special grounds.

A basal factor in all this early evolution of civilization was the productiveness and availability of the soil. The passage from the condition of hunters and fishers, scattered necessarily to adjust themselves to the distribution of game, and shifting with its changes, or from that of simple herders in sterile tracts, roaming with the changes of pasture, in both cases deprived of the evolutionary influences of a fixed abode and of a permanent social and civil organization, was essentially dependent on agriculture, and was hence largely controlled by the permanent fertility of the soil, conjoined with suitable climatic conditions. And so, conversely, among the agencies that have forced the migration of centers of civilization, loss of soil or of soil-fertility, is one of the more important. In the lower latitudes, the upland soils are usually but the residue left by the decomposition of the underlying rocks which has not been removed by surface-wash. Its depth is usually quite limited. With cultivation, wash and wind-drift are accelerated, and unless ample preventive measures are employed, as has not usually been the case in past history, the soils are at length

swept away, and barrenness succeeds productiveness. There are areas in the Orient, once well settled, that are now bare fields of rock on which nothing grows except such few plants as find a foothold in the crevices of the rock. Soils with sandy subsoils have been washed away, leaving barren wastes, and the sands derived from the denuded subsoil have been driven by the winds over adjacent fertile tracts, and by burial have included these in the common waste. The explanation of much of the former richness and of the present poverty of Oriental peoples no doubt lies in this simple process. This impoverishment of soil threatens many peoples to-day, and is in process of actual realization.

The glaciated fields are comparatively new grounds for civilization, and the soil-factor there has a character quite its own. Near the centers of glacial radiation, the old soils were borne away, and new soils were not always developed in equal amount in their stead. A reduced fertility is the result. The half-decayed rock below was largely scraped away, and a long period must ensue before soil-generation will have become effective. These areas lie chiefly in high latitudes where other factors compromise human development in its present state. In the regions of glacial deposition, which fortunately include the greater and the more southerly parts of the glaciated area, a deep sheet of comminuted rock-material, ready for easy conversion into soil by weathering and organic action, covers great plains and has a smoothed topography that aids in restraining its removal. In the peripheral belt of the glaciated area in North America, for a width of 400 or 500 miles, the subsoil of glacial flour and old soil, glacially mixed, has an average thickness of about 100 feet. A similar statement may be made of a large, though less, area in north-central Europe. The average thickness of the residuary soils of unglaciated regions similarly situated is about 5 feet. The twenty-fold provision for permanent fertility thus arising from glaciation seems likely to be a factor of immeasurable importance in the localization of the basal industry of mankind, and of the phases of civilization that are dependent on it.

With the evolution of the industrial arts, resources which were neglected at first have come to play important parts in the distribution and in the activities of the race, among which are the long and growing lists of mineral resources to which economic geology addresses itself. Chief among these are the metallic ores, the fossil fuels, the

mineral fertilizers, and the structural and ornamental materials of stone and clay. These now control man's distribution and his aggregate power, to a degree not even remotely approached a century ago, and they are quite certain to be more influential in the future.

Distribution and activity have also recently come to be affected by the distribution of rejuvenated streams that arose from the deformations of the late Tertiary periods, and by the stream-diversions of the glacial period, both of which have furnished sources of water-power heretofore neglected in the main. With little doubt, such native sources of power are to play an increasingly large part in human affairs as time goes on and the stored fuels are exhausted.

With the increasing complexity of human activities, the localization of the race will more and more depend on *combinations of resources and of conditions*, and less upon single factors; but it is difficult to see beyond the day when persistent fertility of the soil, under favorable climatic conditions, coördinated with great supplies of ores, fuels, and structural materials, will not constitute a decisive and controlling advantage.

Provincialism giving place to cosmopolitanism.—The early history of human dispersal was marked by pronounced provincialism. The early peoples were much isolated from one another by distance and by natural barriers, and they themselves often interposed artificial barriers against free inter-communication, and hence against the preservation of a common cosmopolitan type. So long as hunting and fishing were the dominant pursuits, a wider and wider dispersion into small tribes was a necessary tendency, which was abetted by conflict of interests, strifes and wars, and the sentiments and customs that arose from these. That such artificial sources of provincialism were more effective than the natural ones seems to be implied by the fact that while physiological differences sufficiently marked to readily characterize varieties were numbered by hundreds, dialects sufficiently different to prevent free intercourse were numbered by thousands. Provincial sentiment to-day manifests itself more conspicuously in language than in most other respects. The tendency to provincialism, however, has never gone so far as to divide the race into distinct species, forever separated by infertility.

When efficient water-transportation was developed and the control of the sea was attained, a period of cosmopolitan tendency was

inaugurated, and began to counteract the provincial tendency. This has been greatly accelerated in the past few decades, supplemented by swift land-transportation and by electric communication, and is rapidly involving the whole race in a cosmopolitan movement. Almost the whole world is already in daily communication, and almost all the races are more or less habitually intermingling by travel and trade. That this is to become more and more habitual until the whole race shall be in constant intercommunication, is not to be questioned. There will then have been inaugurated the most marked period of cosmopolitanism, in all senses of the term, which the world has ever witnessed. With this will doubtless come endless blood-mingling, and the racial divergences of the past will be replaced by racial convergences in the future. What this will ultimately mean for the race we will not venture to predict.

Man as a geological agency.—The earlier geologists were inclined to regard man's agency in geological progress as rather trivial, perhaps because physiographic geology, in which his influence is chiefly felt, was then less cultivated than marine, volcanic, and hypogeic geology, in which he scarcely participates. But probably no previous agent in an equal period of time has so greatly influenced the life of the land, both plant and animal, and the rate of land-degradation, as has man since the full inauguration of the present agricultural epoch, and particularly in the last century (Vol. I, pp. 649–651). That this influence will be increased during coming centuries seems clearly foreshadowed. The flora is rapidly passing from that which had been evolved by natural agencies through the long ages, to that which man selects for cultivation or preservation, together with that which has taken advantage of the special conditions he furnishes. With the further progress of this movement, the native floras seem destined to an early extinction. The same may be said of the native faunas. The favored animals, under man's care, flourish beyond precedent, while the rest, so far as they are within his reach, are suffering rapid declines that look toward extinction. The life of the sea is less profoundly affected than that of the land, but even that does not escape important modifications. The most pronounced exceptions to man's dominance, and those that bid fair to contest his supremacy longest, are found in organisms too minute to be easily controlled by man, and in organisms that, quite against his wish, flourish

on the conditions he furnishes. But even the accelerated evolution of these organisms is a part of the profound biological revolution which attends man's dominance.

Man's control has not thus far been characterized by much recognition of the complicated interrelations of organisms and of the consequences of disturbing the balance in the organic kingdom, and he is reaping, and is certain to reap more abundantly, the unfortunate fruits of ignorant and careless action. For the greater part man has been guided by immediate considerations, and even these not always controlled by much intelligence, while great wantonness has attended his destruction of both plant and animal life. But a more intelligent as well as a more sympathetic attitude is developing, and will doubtless soon become dominant.

A new era in control and in evolutionary selection is dawning. New varieties and races are being produced that not only depart widely from the parent stock, but diverge in lines chosen to meet given conditions, or to produce desired products. How far this may yet go it is impossible now to predict. But it may be worth while to suggest that some of the species man is wantonly destroying may possess capabilities of mutation quite beyond present apprehension, and that no species should be allowed to pass utterly beyond reach forever until man shall learn more about its ulterior possibilities.

Prognostic Geology. — The long perspective of the past should afford at least some suggestions of the future, but it must be confessed that the most important previsions are dependent on interpretations of the past that have not yet emerged from the tentative state. A word has been said relative to a possible return of a glacial epoch, but this is contingent on agencies that are yet matters of hypothesis, and no sure prediction can be offered. Question has been raised as to whether the end of the recent period of deformation has come and a gradation into another period of quiescence and equable genial conditions has begun; but the answer hangs on the doctrine of periodicity of deformation and quiescence which does not yet command universal assent, and if it were given, there would remain the further question whether the period of deformation is completed. The duration of the earth as a habitable globe has been a common theme of prognosis. A final refrigeration as the result of the secular cooling of a once molten globe has been the usual forecast, and the final doom of the race has

been a favorite theme for quasi-scientific romances. But this all hangs on the doctrine of a former molten earth, if not also more remotely upon the doctrine of an origin from a gaseous nebula. Under the alternative conception of a slow-grown earth, conserving its energies and giving forth atmosphere as there is need for it, conjoined with a more generous conception of the energies resident in the sun and the stellar system, no narrow limit need be assigned to the habitability of the earth. A Psychozoic era, as long as the Cenozoic or the Paleozoic, or an eon as long as the cosmic and the biotic ones, may quite as well be predicted as anything less. The forecast is at best speculative, but an optimistic outlook seems to us more likely to prove true than a pessimistic one. An immeasurably higher evolution than that now reached, with attainments beyond present comprehension, is a reasonable hope.

The forecast of an eon of intellectual and spiritual development comparable in magnitude to the prolonged physical and biotic evolutions lends to the total view of earth-history, past and prospective, eminent moral satisfaction, and the thought that individual contributions to the higher welfare of the race may realize the fullest fruits of their permanent worth by continued influence through scarcely limited ages, gives value to life and inspiration to personal endeavor.

APPENDIX.

The following sections, from different parts of the United States, supplement the sections already given and convey some idea of the sequence of the known systems in widely separated areas.

SECTION IN WEST CENTRAL MASSACHUSETTS.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Triassic.	Chicopee shale.	200?	Sandy carbonaceous shale.
	Granby tuff.	580	Agglomerate of diabase, interstratified with sandstones.
	Blackrock diabase.		Volcanic cones and dikes of diabase.
	Longmeadow sandstone.	1000	Feldspathic, ferruginous sandstone.
	Sugarloaf arkose.	4660	Feldspathic sandstone and conglomerate (west side of Triassic trough).
	Mount Toby conglomerate.		Basal conglomerate of slate and crystalline rocks (eastern side of Triassic trough).
	Unconformity		
Devonian.	Bernardston series.	1950	Dark mica-schist, with several beds of amphibolite, over quartzite (650 feet) containing a bed of highly crystalline limestone (20 ? feet).
	Unconformity		
Silurian.	Leyden argillite.	300	Black fissile slate.
	Conway schist. Amherst schist. Brinfield fibrolite-schist.	5000?	The Conway schist is a fine-grained, carbonaceous, muscovite-schist, much contorted. The Amherst schist is a rusty mica-gneiss, impregnated with granite. The Conway, Amherst, and Brinfield schists are perhaps geographic variations of the same formation. The granite was probably erupted during the Carboniferous period.
	Goshen schist.	2000?	Dark, flaggy schist with interbedded gneiss.
	Unconformity		
Ordovician.	Hawley schist.	2000?	Green sericite-chlorite schist, with beds of amphibolite and manganese silicates.
	Savoy schist.	5000?	Chloritic, quartzose sericite-schist, with beds of amphibolite, grading into feldspathic mica-schist. Many intrusions of granite.
	Chester amphibolite.	3000?	Epidotic, hornblende-schist, with beds of magnetite and emery near top; contains beds of pyroxene rock, enstatite rock, and dolomite; often replaced by serpentine and steatite.
	Rowe schist.	4000?	Quartzose sericite-schist; sometimes indistinguishable from the Hoosic schist. Some granite.
	Hoosic schist.	1500	Feldspathic mica-schist, with granite.

[1] Emerson, Holyoke (Mass.-Conn.) folio, U. S. Geol. Surv. In the folio, the beds here classed as Triassic are called Jura-Trias, the Ordovician and Silurian are classed together under the name Silurian, and the Proterozoic is called Algonkian.

Section in West Central Massachusetts—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
	Unconformity		
Cambrian.	Becket gneiss.	2000?	White biotite gneiss, locally grading into conglomerate.
	Unconformity		
Proterozoic.	Washington gneiss. *Base not exposed.*	2000?	Rusty biotite-gneiss.

Silurian strata much folded and metamorphosed, but not so severely as the earlier strata. Devonian strata less folded and metamorphosed than the Silurian. Triassic beds tilted and much faulted, though little folded or metamorphosed.

SECTION IN EASTERN TENNESSEE.[1]

System	Names of Formations.	Thickness in Feet.	Characteristics.
Pennsylvanian.	*Summit removed by erosion.* Anderson sandstone.	1000 +	Interbedded with sandy and argillaceous shales and thin coal-beds.
	Scott shale.	500–650	Argillaceous and sandy, with beds of sandstone and thin coal-seams.
	Wartburg sandstone.	500–600	Argillaceous shale, and coal-beds, interbedded.
	Briceville shale.	250–650	Black, bluish-gray, and gray; also thin beds of sandy shale, sandstone, and thick coal-beds.
	Lee conglomerate.	500–1500	Massive sandstone and conglomerate, thin shale-beds, and coal-seams.
	Possible Unconformity		
Mississippian.	Pennington shale.	160–400	Calcareous shale, sandstone, and limestone.
	Newman limestone.	650–700	Massive, blue, with shale-beds. Massive beds of chert and cherty limestone.
Devonian.	Grainger shale.	1200	3. Red and yellow sandy shale. 2. Massive white sandstone. 1. Greenish and bluish-gray; arenaceous.
	Chattanooga black shale	30–50	Black, calcareous.
Silurian.	Clinch sandstone.	6	Present only in one small area.
Ordovician.	Bays sandstone.	300–1100	Red, calcareous.
	Sevier shale.	500–600	Light-blue calcareous shale.
		200–400	Bluish-gray and red calcareous sandstone and shale.
		500–600	Light-blue calcareous slate.
		500–650	Bluish-gray and gray calcareous sandstone and shale.
		500–750	Light-blue, calcareous.
	Tellico sandstone.	800–900	Bluish-gray and gray, calcareous, with some shale.
	Athens shale.	1000–1200	Light-blue and black; calcareous.
	Chickamauga limestone	0–50	Gray, argillaceous.
U.C.	Knox dolomite.	3500	White, gray, light- and dark-blue, with chert.

[1] Keith, U. S. Geol. Surv. Formations above the base of the Mississippian are taken from the Briceville (Tenn.) folio; the remainder from the Knoxville (Tenn.–N. C.) folio. The Ordovician and Silurian formations are classed as Silurian in these folios.

SECTION IN EASTERN TENNESSEE—*Continued.*

	Names of Formations	Thickness in Feet.	Characteristics.
Middle Cambrian.	Nolichucky shale.	450–550	Yellow and brown, calcareous, with limestone-beds.
	Maryville limestone.	350–500	Massive, dark-blue.
	Rogersville shale.	180–220	Bright-green, with a limestone-bed.
	Rutledge limestone.	350–450	Massive, dark-blue.
Lower Cambrian.	Rome formation.	750–950	Red, green, yellow, and brown shales, sometimes sandy and red, white and brown sandstones, and sandy shales.
	Beaver limestone.	300	Massive, blue.
	Apison shale.	200	Green.
		900+	Bright-red, green, and brown; sandy.
	Discontinuity.[1]		
	Hesse sandstone.	500+	Fine, white, massive.
	Murray shale.	300	Grayish-blue, sandy.
	Nebo sandstone.	500	Massive, white.
	Nichols shale.	550–800	Grayish-blue, sandy.
	Cochran formation.	600–900	Massive white sandstone.
		0–100	Red sandstone, gray sandy shale.
		500–700	Coarse conglomerate; quartz, and feldspar pebbles.
	Sandsuck shale. *Base not exposed.*	1000+	Grayish-blue.

Strata much folded and faulted.

[1] See note on preceding page.

SECTION IN EASTERN WEST VIRGINIA AND WESTERN VIRGINIA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Pennsylvanian.	*Summit removed.* Braxton formation.	700+	Red and yellow shale, gray and brown shaly sandstone, and coal-seams.
Pennsylvanian.	Upshur sandstone.	350–500	White and brown, with conglomerate, shale and coal.
Pennsylvanian.	Pugh formation.	300–450	Brown and white sandstone, and blue and black clay; thin coal-seams.
Pennsylvanian.	Pickens sandstone.	400–500	Brown, gray, and white; some conglomerate, and dark shale with coal.
	Unconformity		
Mississippian.	Canaan formation.	1000–1300	2. Red shales and brown sandstones. 1. Thin limestone.
Mississippian.	Greenbrier limestone.	350–400	Includes some red shales.
Mississippian.	Pocono sandstone.	70–90	Coarse and hard, partly conglomeratic.
Devonian.	Hampshire formation.	1500–1800	Sandstones and shales, mainly red.
Devonian.	Jennings formation.	3000–3800	Gray and buff sandstones, with shales.
Devonian.	Romney shale.	1000–1300	Black and fissile below, lighter and more sandy above; thin bed of limestone at base.
	Unconformity		
Devonian.	Monterey sandstone.	50–200	Calcareous, weathers buff.
Devonian. / Silurian.	Lewiston limestone.	550–1050	Thin-bedded, impure limestone, with shale at base; thin flaggy limestone, massive limestone, and cherty limestone in order, above.
Silurian.	Rockwood formation.	100–900	Quartzite at base at the east; shale with thin beds of sandstone, limestone, and iron ore above, and gray sandstone at top.
Silurian.	Cacapon sandstone.	100–630	Red, mainly flaggy.
Silurian.	Tuscarora quartzite.	50–300	White and gray.
Silurian.	Juniata formation.	205–1250	Brownish-red sandstones and red shales.
Ord.	Martinsburg shale.	800–1800	Gray shale; sandy beds near top.
M. & U. C.[2]	Shenandoah limestone.	2400+	3. Light gray, fossiliferous. 2. Darker gray, cherty.
L. C.[3]	*Base not exposed.*		1. Partly magnesian.

Carboniferous strata nearly horizontal; earlier beds folded, but not much faulted.

[1] The section above the Canaan formation is taken from the Buckhannon (W. Va) folio, the remainder from the Monterey (Va.-W. Va) folio. Darton (Monterey) and Taff and Brooks (Buckhannon) U. S. Geol. Surv. In these folios the Ordovician and Silurian are classed as Silurian.
[2] Middle and Upper Cambrian. [3] Lower Cambrian.

SECTION IN NORTHEAST ALABAMA AND NORTHWEST GEORGIA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Pennsylvanian.	*Summit removed by erosion.* Walden sandstone.	500±	Coarse sandstone and sandy shale; beds of coal and fire-clay.
	Lookout sandstone.	60–570	2. Conglomerate with massive sandstone. 1. Sandy shale with coal and fire-clay.
Mississippian.	Bangor limestone.	300	Blue, crinoidal, cherty limestone.
	Oxmoor sandstone.	50–550	White and brown sandstone and conglomerate.
	Unconformity		
	Floyd shale.	2000+	Black, carbonaceous, with occasional beds of crinoidal limestone.
	Fort Payne chert.	20–200	Bedded chert and limestone.
Devonian.	Chattanooga shale.	0–22	Black, carbonaceous.
	Armuchee chert.	0–40	Rusty, sandy chert.
Unconformity			
Silurian.	Rockwood formation.	1000–1500	White, brown, and purple sandstone and sandy shale, with beds of red fossiliferous hematite.
Ordovician.	Chickamauga limestone.	700–1500	Blue flaggy limestone, sometimes purple and mottled, earthy towards the top. Heavy chert conglomerate at the base in places.
Upper Cambrian	Knox dolomite.	1500–4000	Dolomite, white, gray, or light-blue, generally granular and massive; containing nodules and layers of chert.
Middle Cambrian.	Conasauga formation. *Base not exposed.*	1000+	2. Greenish siliceous shale and micaceous sandstone. 1. Olive clay shale.

Strata much folded and faulted.

[1] The two youngest formations in this section are taken from the Gadsden (Ala.) folio, the others from the Rome (Ga.–Ala.) folio. Hayes, U. S. Geol. Surv. In the folio, Ordovician and Silurian are classed together under the name Silurian.

SECTION IN CENTRAL TENNESSEE.[1]

System	Names of Formations.	Thickness in Feet	Characteristics.
Mississippian.	*Summit removed by erosion.* St. Louis limestone.	250	Gray and blue, thick-bedded, fossiliferous; generally very cherty; basal part porous
	Unconformity		
Mississippian.	Tullahoma formation.	0–250	Greenish clay shale at bottom, cherty shale and limestone above
	Unconformity		
Devonian.	Chattanooga shale.	0–10	Black and carbonaceous, generally with phosphatic band at base, and glauconitic green shale, with phosphatic nodules at the top.
	Unconformity		
Silurian.	Clifton limestone.	0–60	Even-bedded, dense, light-gray or bluish; occasionally shaly below.
	Unconformity		
Ordovician.	Fernvale formation.	0–40	Soft green- and chocolate-colored shales, and red, ferruginous, crystalline limestone; occasionally conglomeratic and phosphatic.
	Unconformity		
Ordovician.	Leipers formation.	0–100	In eastern part of quadrangle, knotty, earthy limestone at top, with shaly and highly fossiliferous beds below; in western part, granular, crystalline limestone, the more granular portions highly phosphatic.
	Unconformity		
Ordovician.	Catheys formation.	0–100	Shales and knotty limestones, usually underlain by heavy-bedded subcrystalline limestone, and overlain by fine-grained blue or earthy limestones separated by thin seams of shale. Basal part includes some granular phosphatic layers.
Ordovician.	Bigby limestone.	30–100	Granular, crystalline, laminated, phosphatic limestones; upper part often shaly or arenaceous, lower part has some shale but is never sandy.
Ordovician.	Hermitage formation.	40–70	Even-bedded, alternating, thin layers of argillaceous or siliceous limestone and shale in lower third, and siliceous subgranular limestone, more or less phosphatic, in middle and upper parts.
	Unconformity		
Ordovician.	Carters limestone.	40–60	Heavy-bedded, fine-grained, white or light-blue; often contains chert and silicified fossils.
Ordovician.	Lebanon limestone. *Base not exposed.*	70–100	Thin-bedded, often shaly, bluish or dove-colored.

Strata somewhat warped but nearly horizontal.

[1] Hayes and Ulrich. Columbia (Tenn.) folio, U. S. Geol. Surv.

SECTION FOR SOUTHERN MICHIGAN.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
	Glacial drift, etc.	0–600	Gravel, sand, and clay.
	Unconformity		
Pennsylvanian.	Woodville sandstone.	304+	Gray sandstone grading into blue shale; layers of fire-clay.
	Unconformity		
	Jackson Coal (or Saginaw) series.	47±	Sandy shales of various colors, with layers of fire-clay and beds of coal; charged with iron pyrites; principal coal horizon of Michigan.
	Possible unconformity		
	Parma? sandstone.	0–200	Porous and saturated with brine.
	Unconformity		
Mississippian.	Grand Rapids series.	305±	Limestones, underlain or replaced by shales and dolomite with gypsum.
	Marshall sandstone.	50±	Contains brine.
	Coldwater shales.	667–1000+	Blue arenaceous shales, with seams of fine-grained sandstone. Balls of kidney iron "ore" in some layers.
	Richmondville or Berea sandstone.	65	Contains brine in large amounts; signs of oil and gas.
Devonian.	Antrim (St. Clair) Black shales.	145–300	Often bituminous.
	Traverse group.	100–600	Some limestone in reefs, some dolomite, much blue argillaceous limestone, shales; signs of oil and gas.
	Dundee limestone.	40–160	Light-colored limestone, containing mineral water; some oil and gas.
Silurian.	Monroe formation.	650–2000	Dolomite, with rock salt, gypsum, and glass-sand; brines and mineral waters.
	Niagara formation.	350+	White dolomites and limestone.
Ordovician.	Lorraine and Utica formations.	600	Blue and black shales, with some limestone.
	Trenton limestone.	?	Dolomite and limestone, somewhat oil-bearing.

[1] Lane, Geol. Surv. of Mich., Vol. V, Plate LXXIII, adjusted to nomenclature of Geological Map of Michigan in Geol. Surv. of Mich., Vol. VIII. Section based largely on well-borings at Jackson and Monroe.

GENERALIZED SECTION FOR OHIO.[1]

		Names of Formations.	Thickness in Feet	Characteristics.
		Unconformity		
Permian		Dunkard formation.	525±	Sandstone, generally massive, shales, limestone, and thin coal-seams; non-marine at least in part.
Pennsylvanian		Monongahela formation.	200–250	Shales, limestones, and sandstones, with important beds of coal.
Pennsylvanian		Conemaugh formation.	400–500	Upper part mainly shales; lower part sandstone, with some shale and limestone.
Pennsylvanian		Allegheny formation.	165–300	Shales, limestones, and sandstones, with important coal-seams.
Pennsylvanian		Pottsville conglomerate.	250±	Light-colored sandstones and conglomerates, with some shale and a few coal-seams.
		Unconformity		
Mississippian.		Maxville limestone.	25±	Fossiliferous limestone, often brecciated.
Mississippian.	Waverly series.	Logan group.	100–150	Sandstone, massive conglomerate, and shale.
Mississippian.	Waverly series.	Black Hand conglomerate.	50–500	Sandstone and fine conglomerate.
Mississippian.	Waverly series.	Cuyahoga shale.	150–300	Light-colored, argillaceous shales, with thin beds of sandstone. Shales characterized by ferruginous nodules.
Mississippian.	Waverly series.	Sunbury shale.	5–30	Black bituminous shale.
Mississippian.	Waverly series.	Berea grit.	5–175	Sandstone, used for building-stone and for grindstones; locally carries oil, gas, and brine
Mississippian.	Waverly series.	Bedford shale.	50–150	Thin-bedded shales; occasional thin beds of sandstone.
Devonian.		Ohio shale.	300–2600	Mainly black or dark-brown shale.
Devonian.		Olentangy shale.	20–35	Blue, highly fossiliferous.
Devonian.		Delaware limestone.	30–40	Blue, thin-bedded.
Devonian.		Columbus limestone.	110	Light-colored, often containing chert masses.
Silurian.		Monroe formation.	50–600	Compact magnesian limestone, usually poor in fossils.
Silurian.		Niagara group.	150–350	Light-colored shales at base, dolomitic limestone above, and a thin sandstone bed at top.
Silurian.		Clinton limestone.	10–50	Crystalline, locally replaced by iron ore.
Silurian.		Medina shales (?) (Belfast bed).	50–150	Red or yellow, non-fossiliferous shales, with local thin beds of sandstone.

[1] Prosser, Jour. of Geol., Vol. XI, pp. 520, 521. Geol. Surv. of Ohio, Vols. VI and VII, and Bull. 7, 4th Ser., 1905.

Generalized Section for Ohio—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Ordovician.	Saluda beds.	20±	Mottled clays and thin-bedded limestones.
	Richmond formation.	300±	Alternating beds of shale and limestone, highly fossiliferous.
	Lorraine formation.	300	Alternating beds of shale and limestone, highly fossiliferous.
	Eden (Utica) shale.	250	Black.
	Trenton limestone.	130	Light to dark-blue, crystalline, massive-bedded and fossiliferous; the most important oil and gas horizon of the State.

Strata dip at low angles.

GENERALIZED SECTION FOR INDIANA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Quaternary.	Glacial and post-glacial deposits.	0–385	Sand, clay, and gravel.
	Unconformity		
Permian or Triassic.	Merom sandstone.	60+	Massive sandstone.
	Unconformity		
Pennsylvanian.	Coal Measures.	300–800	Shales, clays, sandstones, limestones, and coal.
	Mansfield sandstone.	0–125	Massive.
	Unconformity		
Mississippian.	Kaskaskia.	120	Sandstone and limestone.
	Mitchell limestone.	0–250	Massive.
	Bedford Oolitic limestone.	20–80	Excellent building-stone.
	Harrodsburg limestone.	60–90	
	Knobstone. Rockford goniatite limestone.	40–600	Arenaceous shales and sandstones; thin limestone at base.
Devonian.	New Albany Black shale.	70–120	
	Brown shale.	25–47	
	Hamilton formation.	47	Limestone and shale.
	Corniferous.	5–85	Limestone and sandstone.
Silurian.	Lower Helderberg(?) formation [2]	25–230	Limestone.
	Waterlime formation.	65–150	Limestone.
	Niagara formation.	50–450	Limestone and shale.
	Clinton and Medina formations.	0–100	Limestone, etc.

[1] Blatchley and Ashley, Indiana Dept of Geol. and Nat. Res., 22d Ann. Rep., 1897, Pl. II.
[2] If this is really the Helderberg formation, it should be classed as Devonian, according to the classification here adopted.

GENERALIZED SECTION FOR INDIANA—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Ordovician.	Hudson River formation.	260–860	Limestones, clays, and shales.
	Utica shale.	0–300	
	Galena and Trenton limestone.	486–525	
	St. Peters sandstone.	150–224	
	Lower Magnesian limestone.	50+	
Upper Cambrian.	Potsdam sandstone. *Base not exposed.*	1000±	

GENERALIZED SECTION FOR IOWA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
	Glacial drift.	125	
	Unconformity		
Upper Cretaceous	Benton formation.	0–150	Shale, chalk, and thin-bedded limestone.
Upper Cretaceous	Dakota formation.	50–100	Shales, sometimes calcareous; and sandstone, sometimes concretionary. Thin bands of lignite. Non-marine in part at least.
	Unconformity		
Pennsylvanian.	Missouri formation.	1500	Mainly light-colored, calcareous shales, grading into pure limestone; limited amounts of bituminous shales; few seams of coal of economic importance.
Pennsylvanian.	Des Moines formation.	250–400	Clay-shales, often highly bituminous; sandstones, often in thick layers; limestones in thin bands; important coal-beds.
	Unconformity		
Mississippian.	St. Louis limestone.	100	Light, ash-colored limestones, and marls, with thin beds of sandstone. Good building stone.
Mississippian.	Osage (Augusta) formation.	200–300	Buff limestone and shales, underlain by coarse-grained encrinital limestone; basal portion usually ferruginous; prominent chert-beds.
Mississippian.	Kinderhook formation.	150–200	Bluish or greenish clay shales, fine-grained; buff, compact, more or less argillaceous limestones; sandstones.
Devonian	Lime Creek formation.	80	Dark-colored argillaceous shales, highly fossiliferous, and locally calcareous.
Devonian	State Quarry beds.	20–40	Light gray; good building-stone. Fish teeth.
Devonian	Sweetland Creek shales.	20–40	Black and greenish; Upper Devonian fossils.
Devonian	*Unconformity*		
Devonian	Cedar Valley limestone	250–300	Pure to argillaceous limestone and dolomite; sometimes massive, sometimes finely laminated, frequently brecciated.
Devonian	Wapsipinicon formation. (Independence, Fayette, Davenport.)	100–150	Carbonaceous shales with bands of impure concretionary limestone; brecciated limestone.
Silurian.	Anamosa limestone.	50–75	Soft, granular, evenly bedded dolomite; white to buff and gray; important building-stone.
Silurian.	Le Claire limestone.	50	Massive or heavy-bedded highly crystalline dolomite. Upper surface undulating; cross-bedded on a large scale.
Silurian.	Delaware stage.	200	Limestone containing large quantities of chert.
	Unconformity		

[1] Reports of Iowa Geol. Surv.

GENERALIZED SECTION FOR IOWA—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Ordovician.	Maquoketa shales.	175	Drab, gray, and black; calcareous in parts.
	Possible unconformity		
	Galena-Trenton limestone.	290	*Galena phase*, dark buff, granular, highly crystalline dolomite. Upper portions argillaceous. *Trenton phase*, alternating beds of shale and non-magnesian limestone; green, buff, and blue.
	St. Peters sandstone.	100	White, brown, yellow, red; coarse and friable.
	Oneota formation (includes Shakopee, New Richmond and Oneota proper).	300	Dolomite with some interstratified sandstone.
Cambrian	St. Croix sandstone.	1000+	Slightly consolidated, disintegrating rapidly on weathering; includes thin, argillaceous, and calcareous seams, and some greensand.
Proterozoic	Sioux quartzite.	?	Hard, vitreous quartzite grading locally into loose sandstone; color usually red to dark purple, or almost white.

SECTION FOR ARKANSAS.[1]

		Names of Formations.	Thickness in Feet.	Characteristics.
Pennsylvanian		Potea beds.	3500	Mainly shales and sandstones with some coal-beds.
		Productive beds.	1800	
		Barren beds.	18480	
		Discontinuity.		
		Millstone grit.	500	Sandstones and conglomerates; friable to hard; buff or brown, with occasional seams of limonite.
Mississippian.	Boston group	Kessler limestone.	3–15	Thin-bedded.
		Coal-bearing shale.	60–90	Shale, in places highly fossiliferous; thin coal-seams.
		Pentremital limestone.	0–90	Impure, dark-colored, and loose-textured; sometimes interbedded with sandstone.
		Washington sandstone and shale.	40–75	Varying proportions of sandstone and gray shale.
		Archimedes limestone.	0–80	Light-gray limestone, rich in Archimedes.
		Marshall shale.	0–250	Black, bituminous.
		Batesville sandstone.	10–200	Sometimes massive; sometimes thin-bedded.
		Spring Creek Black shales and limestone.	300	Shales and limestones, black to bluish or yellowish brown in color.
		Wyman sandstone.	0–9	
		Boone chert.	370	Interbedded chert and limestone; contains the St. Joe marble, 25–40 feet.
		Eureka shale.	0–50	Thin-bedded, black.
Devonian		Sylamore sandstone.[2]	0–40	Hard or saccharoidal.
		Unconformity		
Silurian.		St. Clair limestone and Carson shale.	80	Underlain by shales which locally bear manganese ore and phosphates in commercial quantities.
		Unconformity		

[1] Branner, Amer. Jour. Sci 4th series, Vol. 2, 1896, p 235; Hopkins, Ark. Geol. Surv. Ann Rept. 1890, Vol IV, pp. 10, 90–125, 253; Penrose, Ark. Geol Surv. Ann Rept. 1890, Vol. I, pp. 113–197, 215; Williams, Ark Geol. Surv. Ann. Rept. 1892, Vol. V, pp. 273–356; Taff, 22d Ann. Rept. U. S. Geol. Surv. Part III, pp. 389–392. Section above the Millstone grit is for the Arkansas valley region. Section below this region is for northern Arkansas.

[2] Sylamore sandstone usually given as the Phosphate horizon, but unpublished work places it in the Carson shale.

Section for Arkansas—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Ordovician.	Polk Bayou limestone.	75	Highly crystalline limestone in massive layers; light gray to chocolate-brown.
	Izard limestone.	285	Fine-grained; compact, non-fossiliferous, evenly bedded; mainly dark blue, but varies to buff, light gray, and almost black.
	Saccharoidal sandstone.	125	Friable; usually white, but often brown; sometimes quartzitic.
	Calciferous or Magnesian limestone.	1625	Brownish-gray arenaceous dolomite, few fossils.

SECTION IN INDIAN TERRITORY.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Pennsylvanian.	*Summit removed by erosion.* Seminole conglomerate.	50+	Conglomerate of white chert in brown sandy matrix, succeeded by brown sandstone.
	Holdenville shale.	260	Blue and yellow clay shale, with thin siliceous limestone- and sandstone-beds.
	Wewaka formation.	700	Massive brown friable sandstone, with soft, thin limestone lentil in lower part.
	Wetumka shale.	120	Clay shale above, sandy shale and thin sandstone below.
	Calvin sandstone.	145–240	Thick-bedded and hard, friable, ferruginous, and shaly towards the south.
	Senora formation.	140–485	Brown sandstone, thick-bedded to shaly.
	Stuart shale.	90–280	Blue and black, with sandstone lentil.
	Thurman sandstone.	80–260	Brown sandstone, shale, and cherty conglomerate.
	Boggy shale.	2000–2600	Shale, shaly sandstone, and brown sandstone. Locally, thin siliceous limestone-beds, and coal near the base.
	Savannah sandstone.	750–1100	Brown sandstone and shale.
	McAlester shale.	1150–1500	Shale, brown sandstone, and conglomerate of white chert pebbles.
	Hartshorne sandstone.	150–200	Brown sandstone, varying to chert conglomerate.
	Atoka formation (Chickahoc chert lentil).	3200	Shale and brown sandstone variable in thickness, texture, and hardness. Lentil of chert and limestone, and a conglomerate bed of iron concretions.
	Wapanucka limestone.	100–150	White oölitic and blue limestone, shale, and locally cherty calcareous sandstone.
Mississippian.	Caney shale.	1500	2. Blue shale with sandy lentils and ironstone concretions. 1. Black fissile shale, with dark-blue fossiliferous limestone concretions.
Devonian.	Woodford chert.	600	Thin-bedded chert and fissile black shale; blue flint lentils at base.

[1] Above the Savannah sandstone the section is taken from the Coalgate (I. T.) folio; remainder from the Atoka folio. Taff, U. S. Geol. Surv. In the area covered by the Talequah folio, there are unconformities between the Ordovician and the Silurian, the Silurian and the Devonian, the Devonian and the Mississippian, and the Mississippian and the Pennsylvanian.

SECTION IN INDIAN TERRITORY—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Silurian.	Hunton limestone.	160	Light-colored, with flint and chert concretions in the upper part.
Silurian. / Ordovician.	Sylvan shale.	50–100	Blue clay shale.
Ordovician.	Viola limestone.	750	White, bluish, with flint concretions in the middle.
Ordovician.	Simpson series.	1600	5. Sandstone, calcareous sandstone, and shale (at top). 4. Thin fossiliferous limestone and shale. 3. Calcareous sandstone and shale. 2. Fossiliferous limestone and shale. 1. Sandstone and shaly beds.
Ordovician.	Arbuckle limestone.	4000–6000	White and blue, partly massive and partly thin-bedded.
Cambrian.	Regan sandstone.	50–100	Coarse, dark brown.
	Unconformity		
Pre-Cambrian.	Tishomingo granite.	?	Coarse red granite with dikes of basic rock.

Strata folded and faulted.

GENERALIZED SECTION FOR NEBRASKA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Quaternary.	Alluvium.		
	Sand-hills.		Mainly dunes.
	Loess.		Fine sandy loam of pale brownish-buff color.
	Glacial drift.		
	Equus beds.		Gray sands; eolian in part.
Pliocene?	Ogallala formation.	150–300	Calcareous grit, sandy clay, and sand; largely fluvatile.
Miocene.	Arikaree formation.	0–500	Gray sand with beds of pipy concretions; fluvatile and eolian.
	Gering formation.	0–200	Coarse sands, soft sandstone, and conglomerate; largely fluvatile.
Oligocene.	Brule clay.	320–600	Pinkish clays, hard, and more or less arenaceous; fluvatile and lacustrine.
	Chadron formation.	30–60	Pale greenish-gray sandy clay; fluvatile or lacustrine or both.
Cretaceous.	Pierre clay.	2000+	Dark gray and soft; marine.
	Niobrara formation.	50	Chalky limestone and shale; marine.
	Benton shale.	600+	Dark gray or black; marine.
	Dakota sandstone.	400	Brown; probably non-marine in part at least.
Permian.	Permian limestone.	200	Buff limestones and shales; marine.
Pennsylvanian.	Cottonwood limestone.	1000	Massive, of light color.
	Wabaunsee formation.		Limestones, shales, sandstones, and thin coal-beds.

Strata nearly horizontal.

[1] Darton, 19th Ann. Rep., Part IV, p. 732, U. S. Geol. Surv.; also Scotts Bluff (Nebraska) folio, U. S. Geol. Surv.

SECTION IN EASTERN WYOMING.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Quaternary.	Alluvium.	1–30	Gravel, sand, and silt.
Neocene.	Arikaree formation.	700+ 30–40	2. White sand and soft sandstone, with pipy concretions; non-marine. 1. Gray sandstone and conglomerate.
Oligocene.	Brule formation.	250	Flesh-colored sandy clay, with lenses of sandstone; non-marine.
Oligocene.	Chadron formation.	60+	Green, maroon, and pink sandy clay and gray sandstone; non-marine.
	Unconformity		
Cretaceous.	Graneros formation (Colorado).	120+	Gray flaky shale, with concretions and massive sandstone near top; non-marine.
Cretaceous.	Dakota sandstone.	250–300	Massive buff, gray, and reddish sandstone and quartzite, with thin beds of clay and shale; non-marine.
	Unconformity		
Triassic and Jurassic.	Morrison clay. (*May be Lower Cretaceous.*)	100	Clays of various colors, with a thin bed of limestone; probably non-marine.
Triassic and Jurassic.	Sundance formation.	200	Buff sandstone, with interbedded clays near top; marine.
Triassic and Jurassic.	Spearfish sandstone. ("Red beds," possibly Permian.)	450	Dark reddish-brown, medium-grained, thin-bedded; limestone beds, and thin sheets of gypsum in lower parts; salt lake deposits.
Permian.	Minnekahta limestone.	20	Gray to purplish, thin-bedded.
Permian.	Opeche formation.	60	Bright-red, thin-bedded sandstone, with red, flaky shale; marine.
Pennsylvanian.	Hartville formation.	650	3. Massive gray limestone, some beds cherty; occasional beds of white, gray, buff, and red sandstone. 2. Red shale and gray limestone. 1. Red quartzite streaked with white.
	Unconformity		
Mississippian.	Guernsey formation.	150	Conglomeratic quartzite, with sandstone and gray limestone above.
	Unconformity		
Proterozoic[2]	Whalen group and intrusive granite.		Quartzite, schist, siliceous limestone, and gneiss. Masses and dikes of intrusive granitic rocks.

Strata horizontal or with gentle dips.

[1] Smith, W. S. T., Hartville Wyo., folio, U. S. Geol. Surv.
[2] Proterozoic given as Algonkian in folio.

GENERALIZED SECTION FOR THE BLACK HILLS.[1]

		Names of Formations.	Thickness in Feet.	Characteristics.
Oligocene.		White River formation.	0–200	Porous, crumbling clay, with coarse sandstone and conglomerate; non-marine deposits, commonly classed as lacustrine.
Upper Cretaceous.		Laramie formation	2500	Massive sandstone and shale; mainly non-marine.
	Montana.	Fox Hills formation.	250–500	Sandstone and shale; marine.
		Pierre shale.	1200	Dark gray; marine.
	Colorado.	Niobrara formation.	225	Chalk and calcareous shale; marine.
		Carlile formation.	500–750	Gray shales with thin sandstone, limestone, and concretionary layers; marine.
		Greenhorn limestone.	50	Impure, slabby; marine.
		Graneros shale.	900	Contains lenses of massive sandstone; marine.
		Dakota sandstone.	35–150	Massive, buff; non-marine, at least in part.
Lower Cretaceous.		Fuson formation.	30–100	Fine-grained sandstone, and massive shales; white to purple; no fossils.
		Minnewaste limestone.	0–30	Gray; no fossils.
		Lakota formation.	200–350	Massive buff sandstone, intercalated shale; largely non-marine. Fossils cycads.
		Morrison shale.	0–125	Massive, and of gray, green, and maroon colors; thin beds of sandstone.
		Unconformity		
Jurassic.		Beulah shale.	0–150	Pale grayish green; marine.
		Unkpapa sandstone.	0–250	Massive, white, purple, red, and buff; marine, shallow-water deposits.
		Sundance formation.	60–400	Dark drab shales and buff sandstones; massive red sandstone at base; marine, shallow-water deposits.
Triassic.		Spearfish formation.	350–500	Red sandy shales with gypsum-bed; salt lake deposits.
Permian(?).		Minnekahta limestone.	30–50	Thin-bedded, gray; marine.
		Opeche formation.	90–130	Red slabby sandstone, and sandy shale; marine.

[1] Darton, 21st Ann. Rep. U. S Geol. Surv., Part IV, pp. 503–504, and Darton and Smith, Edgemont folio, U. S Geol. Surv. Ordovician inserted from Jaggar, 21st Ann. Rept., Part III, U. S. Geol. Surv., pp. 178–181.

GENERALIZED SECTION FOR THE BLACK HILLS—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Pennsylvanian.	Minnelusa formation.	400–450	Sandstones, mainly buff and red; in greater part calcareous; some thin limestone included.
Mississippian.	Pahasapa limestone.	250–500	Massive gray limestone.
	Englewood limestone.	25	Pink, slabby limestone.
Ordovician.	Ordovician.	80	Massive limestone, usually buff with brown or reddish spots. Present only in northern Black Hills region.
Cambrian.	Deadwood formation.	4–150	Red-brown quartzite and sandstone, locally conglomeratic.
	Unconformity		
Pre-Cambrian.			Crystalline schists.

SECTION IN CENTRAL MONTANA.[1]

		Names of Formations.	Thickness in Feet.	Characteristics.
Quaternary.		Alluvium.	0–50+	
		Glacial drift.	0–100+	
		Unconformity		
Tertiary (Neocene).		Smith River beds.	0–800	Clay, sand, conglomerate, and tuff; vertebrate remains; non-marine.
		Unconformity		
Cretaceous.		Livingston formation.	3300	Dark-brown tufaceous sandstone, with local beds of conglomerate, shale, limestone, and pyroclastic materials. Estuarine or lacustrine conditions, followed by land conditions, and then by marine.
		Unconformity		
		Laramie formation.	900–1050	Light-gray or yellow sandstone; shale-beds in upper portion; workable seams of coal; plant remains and brackish-water shells.
	Yellowstone Series.	Montana formation. Colorado formation. Dakota formation.	2800–3500	4. Lead-gray arenaceous shale, with thin beds of sandstone; marine. 3. Calcareous shale with limestone concretions and interbedded sandstones; marine. 2. Black bituminous shale. 1. Quartzite; sandy shale below and conglomerate at base; fresh-water fossils in limestone near top; fluvatile or lake deposits.
Jurassic.		Ellis formation.	90–120	Arenaceous limestone and shale; marine.
Mississippian.		Quadrant formation.	1400	5. Alternating beds of limestone and sandstone. 4. Green shale with interbedded limestones. 3. Limestone with sandstone beds. 2. Green shale with interbedded limestones, often oölitic. 1. Red clay with yellow lumps. All shallow-water, marine deposits
		Madison limestone	1025	Massive and white above, thin-bedded, dark gray below.
Dev. & Sil.?		Monarch formation.	165	Chocolate-brown, granular limestone.

[1] Weed, Little Belt Mts. (Mont) folio, U. S Geol. Surv. Combination of the sections there given. Ellis formation classed as Jura-Trias in the folio What is here marked *Yellowstone series* is given as *Yellowstone formation, Belt series* as *Belt formation, Barker series* as *Barker formation*, and Proterozoic as Algonkian.

SECTION IN CENTRAL MONTANA—*Continued.*

Names of Formations.			Thickness in Feet.	Characteristics.
Middle Cambrian.	Barker Series.	Gallatin limestone. Flathead quartzite.	1300	3. Massive and thin-bedded limestone. 2. Dark-green and purple micaceous shale, with interbedded limestone and limestone conglomerate. 1. Pink quartzite and sandstone.
Unconformity				
Proterozoic.	Belt Series.	Spokane shale. Greyson shales. Newland limestone. Chamberlain shale.	210 950 560 2080	4. Red. 3. Lustrous gray sericitic shale and slate. 2. Dense, dark-colored, bluish gray, impure, with interbedded slate. 1. Slate, and compact, indurated, dark-gray shale.
Proterozoic.		Neihart quartzite.	700	Massive-bedded.
Unconformity				
Archean.				Banded gneiss and mica schist, with intrusive porphyries, diorite, and syenite.

Paleozoic and Mesozoic strata folded, faulted, and cut by igneous rocks. Tertiary beds nearly horizontal.

Section in West Central Colorado.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Eocene or later	West Elk breccia.	3000	Upper part volcanic breccia; lower part friable tuff, with sandstone beds. Material mainly dark hornblende-andesite and pyroxene-andesite, with some non-eruptive débris in the lower part.
	Unconformity		
Cretaceous.	Ruby formation.	2500	Conglomerate, sandstone, and shale alternating; chiefly of igneous débris, with quartz sand intermingled; conglomerate at base; probably non-marine.
	Unconformity		
	Ohio formation. (Local only.)	200	Quartzose sandstone, with vari-colored jasper and clay at base; probably non-marine.
	Unconformity		
	Laramie formation.	2000	Sandstone and shale with workable coal-beds in the lower 400 feet; arenaceous shale predominates in upper half. The coals are anthracite (subordinate), coking, and dry bituminous. Sand and shallow-water deposits; partly non-marine.
	Montana formation.	2800	Fine-grained yellow sandstone (Fox Hills) in upper part, 300 feet; lead-gray shale, with numerous lenticular bodies of limestone (Pierre formation) below; marine.
	Niobrara formation.	100–200	Upper two thirds gray, calcareous shale; the lower third light-gray limestone; marine.
	Benton formation.	150–300	Black shale, with thin limestone-beds near top; ironstone; marine.
	Dakota formation.	40–300	White quartzite; conglomerate at the base; local fire-clays; non-marine in part at least.
Jurassic.	Gunnison formation.	350–500	Upper two thirds drab, green, yellow, and pink clays, with thin beds of limestone. Heavy white quartzite below; non-marine.
	Unconformity		
Pennsylvanian.	Maroon conglomerate.	2500	Conglomerate and sandstone in heavy beds; material chiefly from the Archean, but the conglomerate contains limestone derived from the earlier Carboniferous beds. Occasional thin beds of fossiliferous limestone.
			Possible unconformity
		2000	Quartzose, conglomerate, grit, and sandstone, with pebbles derived from Carboniferous below. Thin beds of fossiliferous limestone.
	Possible unconformity		
	Weber limestone.	100–550	Dark-gray to black shale, with thin beds of limestone carrying black chert.
	Unconformity		

[1] Emmons, Cross, and Eldridge, Anthracite and Crested Butte, Col., folio, U. S. Geol. Surv.

SECTION IN WEST CENTRAL COLORADO—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Mississippian.	Leadville limestone.	400–525	The upper third massive, blue, and cavernous; the lower two thirds bedded, gray to brown; dark cherts.
	Apparent unconformity		
Ordovician.	Yule limestone.	350–450	80 feet of green, pink, and yellow shale and thin limestone at top; middle portion massive gray limestone with white chert.
Upper Cambrian.	Sawatch quartzite.	50–350	Upper two thirds red quartzite, containing glauconite. The lower third quartzite with conglomerate at base.
	Unconformity		
Archean.	Archean.		Granite, gneiss, and schist.

Strata folded, faulted, and cut by igneous intrusions.

GENERALIZED SECTION FOR SOUTHWESTERN COLORADO.[1]

		Names of Formations.	Thickness in Feet.	Characteristics.
Tertiary.		Potosi volcanic series.	1250	Alternating rhyolite and quartz-latite flows and tuffs, flows predominating near base. Some thin upper flows in Potosi Peak are glassy.
		Unconformity		
	Silverton volcanic series.		100–3000	Andesite flows, tuffs, and dikes, with both augite and hypersthene.
		Unconformity		
		Burns latite.	1200	Flows, tuffs, breccias, and dikes of dark hornblendic quartz-bearing latite of andesitic habit.
		Unconformity		
		Eureka rhyolite.	1800	Massive flows, dikes, and bedded tuffs, the former greatly predominating.
		Unconformity		
		Picayune andesite.	500	Augite-andesite tuff, breccia, or agglomerate, and massive flows. Base not known.
		Unconformity		
		San Juan tuff.	100–2000	Almost exclusively andesitic débris. Well stratified near base, coarser and less distinctly bedded above. No fossils known.
		Unconformity		
		Telluride conglomerate.	0–200	Contains pebbles and bowlders of schist, granite, and quartzite, with some Paleozoic limestones and other sediments. Thickens westward to 1000 feet, and here includes sandstones and shales.
		Unconformity		
Permian?		Cutler formation.	1000 +	Bright-red sandstones and pinkish grits and conglomerates, alternating with reddish sandy shales and limestones.
Pennsylvanian.		Rico formation.	300	Dark red-brown sandstone and pink grits, with intercalated greenish or reddish shale, and sandy, fossiliferous limestone.
		Hermosa formation.	2000	Limestones, grits, sandstones, and shales. Heavy bedded limestone predominates in middle and upper parts, sandstone and shale below. Fossils numerous.
		Molas formation.	75	Red calcareous shale and sandstone, with thin, fossiliferous limestone lenses, and chert, limestone, and quartzite pebbles.
		Unconformity		

[1] Cross and Howe, Silverton folio, U. S. Geol. Surv.

Generalized Section for Southwestern Colorado—*Continued.*

	Names of Formations.	Thickness in Feet.	Characteristics.
Mississippian. / Devonian.	Ouray limestone.	200+	Pale yellow to buff, compact; lower third shaly, with thin quartzites; abundant fossils indicate, Devonian age of lower two thirds, and Mississippian age of upper part.
Devonian.	Elbert formation.	25–100	Thin limestone, sandstone, and calcareous shale; contains fragmentary remains of fishes.
	Unconformity		
Cambrian.	Ignacio quartzite.	0–200	Light gray, pink, or yellow; massive and conglomeratic below, thin-bedded with shale or sandy partings in medial zone, massive above. *Obolus* sp. ? found near middle.
	Unconformity		
Proterozoic.	Uncompahgre formation.	8000+	Massive white or smoky quartzite and dark slate, alternating in thin beds locally. No fossils found.
Archean.			Schist and gneiss of light and dark colors, often alternating. Intruded by granite and cut by basic dikes, many of which have been mashed.

GENERALIZED SECTION FOR THE GRAND CANYON REGION.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Tertiary.	Tertiary.	815	Marls and shales, with sandstone and limestone. Fresh- and brackish-water deposits.
Cretaceous.	Cretaceous.	3095	Soft, more or less calcareous sandstones and dark argillaceous and carbonaceous shales containing extensive beds of coal; mainly marine, in part non-marine.
Triassic and Jurassic.	Jurassic.	960	3. Bright-red calcareous and gypsiferous shales, with some sandstone; in part marine. 2. Massive white sandstone; probably marine.
	Jura-Trias.	3430	1. Red and buff sandstones, with beds of shale and gypsum; largely non-marine.
Permian.	Upper Permian.	710	Gypsiferous and arenaceous shales and marls; shaly limestone at the base; partly non-marine.
	Unconformity		
	Lower Permian.	145	Similar to the above, with more massive limestone at the base; largely marine.
	Unconformity		
Pennsylvanian.	Upper Aubrey limestone.	805	Massive, cherty limestone with arenaceous gypsiferous bed; calciferous sand rock below.
	Lower Aubrey sandstone.	1485	Friable, reddish sandstone, becoming more compact and massive below; a little limestone.
Mississippian.	Red Wall limestone.	962	Arenaceous and cherty limestone above, with massive limestone and chert below.
	Unconformity		
Devonian.	Temple Butte limestone.	94	Impure limestone and sandstone.
	Unconformity		
M. & U. Cambrian.	Tonto series.	1050	Calcareous and arenaceous shales above, sandstone below.
	Unconformity		
Proterozoic.	Chuar.	5120	Shales, sandstones, and thin beds of limestone.
	Unkar.	6830	Sandstones, shales, interbedded lavas, and some limestone.
	Great unconformity		
Archean.	Vishnu.	1000+	Schists, gneisses, etc., with dikes and veins of granite.
	Base not exposed.		

[1] Walcott, Jour. of Geol., Vol. III, pp. 317–324; Bull. Geol. Soc. Amer., Vol. I, p. 50; Amer. Jour. Sci., 3d series, Vol. 20, 1880, p. 222. Dutton, Tertiary History of the Grand Canyon, pp. 35, 40. Vishnu is classed as Algonkian in some of the above.

SECTION IN ARIZONA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Comanchean (Bisbee group).	Centura formation.	1800+	Red nodular shales with cross-bedded, buff, tawny, and red sandstones; beds of impure limestone near base.
	Mural limestone.	650	Thick-bedded, hard, and fossiliferous above, and thin-bedded, arenaceous, and fossiliferous below.
	Morita formation.	1800–2000+	Buff, tawny, and red sandstones, and dark-red shales, with occasional thin beds of impure limestone near the top.
	Glance formation.	25–500	Bedded conglomerate; pebbles angular and chiefly of schist and limestone.
	Unconformity		
Pennsylvanian.	Naco limestone, with intruded granite porphyry.	3000+	Chiefly light-gray, compact limestone, in beds of moderate thickness; fossils abundant.
Mississippian.	Escabrosa limestone.	700	Thick-bedded white, and light-gray limestone, with abundant crinoid stems.
Devonian.	Martin limestone.	340	Dark-gray, fossiliferous.
	Unconformity		
Cambrian.	Abrigo limestone.	770	Thin-bedded, impure, cherty.
	Bolsa quartzite.	430	Cross-bedded, with basal conglomerate.
	Unconformity		
Pre-Cambrian.	Pinal schist.		Sericitic schists.

[1] Ransome, Bisbee, Ariz., folio, U. S. Geol. Surv.

SECTION IN THE EUREKA DISTRICT, NEVADA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Pennsylvanian.	Upper Coal-measures	500	Light-colored blue and drab limestones.
	Weber conglomerate.	2000	Coarse and fine conglomerates, containing chert and layers of reddish-yellow sandstone.
	Lower Coal-measures. *Transition fauna at base.*	3800	Heavy bedded dark-blue and gray limestone, with intercalated bands of chert, argillaceous beds near base.
Missis-sipian.	Diamond Peak quartzite.	3000	Massive gray and brown quartzite, with shales at summit.
Devonian.	White Pine shale.	2000	Black, sometimes arenaceous, with intercalations of friable sandstone, varying from point to point.
	Nevada limestone.	6000	Massive to thin-bedded, of variable color and texture; highly fossiliferous.
Silu-rian.	Lone Mountain limestone.	1800	Trenton fossils at base; Silurian fossils above.
	Unconformity		
Ordovician.	Eureka quartzite.	500	Compact and vitreous, white, and blue, reddish near base.
	Pogonip limestone.	2700	Interstratified limestones, argillites; arenaceous beds at base; fine-grained, bluish-gray. Limestone distinctly bedded above; highly fossiliferous. Mingling of Cambrian and Ordovician fossils at the base.
Upper Cambrian.	Hamburg shale.	350	Chert nodules abundant, especially near the top.
	Hamburg limestone.	1200	Dark gray and granular; only slight traecs of bedding.
	Secret Canyon shale.	1600	Yellow and gray argillaceous shales, passing into shaly limestone; interstratified layers of shale and thin-bedded limestones near top.
Middle Cambrian.	Prospect Mountain limestone.	3050	Gray, compact limestone, bedding planes imperfect. Olenellus fauna at base.
Lower Cambrian.	Prospect Mountain quartzite.	1500	Bedded brownish-white quartzite; layers of arenaceous shale; no fossils.

[1] Hague, Mon. XX, pp. 13–87, U. S. Geol. Surv., and Walcott, Mon. VIII, U. S. Geol. Surv pp. 8 and 283.

SECTION IN SOUTHERN CALIFORNIA.[1]

	Names of Formations.	Thickness in Feet.	Characteristics
Quaternary.	Alluvium, etc.	1–100	Clay and gravel.
	Terrace deposits and dune sand.	10–400 ±	Sand and gravel.
Pliocene (?).	Paso Robles formation.	1000 +	Sandy and marly clay, with pebbly conglomerate; fragments of Monterey shale at bottom.
	Unconformity		
Miocene (?).	Pismo formation (*in south part of area*).	3000 ±	Sandstone and conglomerate at the base, siliceous shale, diatomaceous earth, and soft sandstone above.
	Santa Margarita (*in north part of area*).	1550 ±	Alternations of conglomerate and sandstone, with layers of diatomaceous earth and pumice.
	Unconformity		
Miocene.	Monterey shale.	5000–7000	Thin-bedded bituminous shale, largely siliceous, with diatomaceous earth in places; carries oil and asphaltum. Toward base, limestone, with volcanic ash below, and sandstone at bottom.
	Vaquero sandstone.	0–500	Sandstone and conglomerate.
	Unconformity		
Cretaceous.	Atascadero formation.	3000–4000	Sandstone with some conglomerate and shale.
	Unconformity		
Comanchean.	Toro formation (Knoxville.)	3000 ±	Dark clay shale, with irregular beds of conglomerate at bottom and near the middle.
	Unconformity		
Jura-Trias.	San Luis formation (Franciscan).	1000 ±	Chiefly sandstone, but locally much shale; numerous radiolarian jasper lentils, and some contact metamorphic schist.
	Unconformity		
	Granite.		

[1] Fairbanks, San Luis folio, U. S. Geol. Surv. The Comanchean and Cretaceous are classed as Cretaceous in the folio.

SECTION IN CENTRAL WASHINGTON.[1]

	Names of Formations.	Thickness in Feet.	Characteristics.
Pliocene.	Rhyolite	100–800	Compact lava and tuff.
	Unconformity		
Eocene.	Roslyn formation.	3500±	Massive yellow sandstone with some shale. Roslyn bed of coal in upper part, and other less valuable beds at other horizons.
	Teanaway basalt.	300–4000	Lava-flows with interbedded tuffs; lava black and dark gray, compact or vesicular, sometimes weathering brown or red.
	Unconformity		
	Swauk formation.	3500–5000	Conglomerate schist and quartzose sandstone and shale, of light and dark colors; cut by numerous dikes of diabase.
	Unconformity		
Pre-Tertiary.	Igneous and metamorphic rocks.		

[1] Smith, G. O., Mt. Stuart folio, U. S. Geol. Surv. The section given is for the northern part of the Mt. Stuart quadrangle. In its southern part, Miocene, consisting of igneous rocks, Taneum andesite and Yakima basalt below, and of the Ellensburg formation above, overlie the Eocene.

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VOLUMES I, II, AND III.

INDEX.

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